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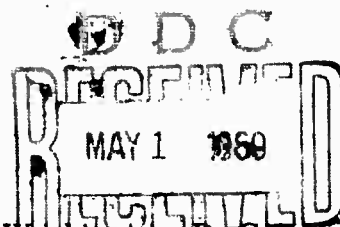
NIGHT VISION AIDS FOR COUNTERINSURGENCY
First Annual Report
3 March 1966 Through 3 March 1967

By

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Willow Run Laboratories
Institute of Science and Technology
The University of Michigan
Ann Arbor, Michigan

May 1968



Prepared for the Advanced Research Projects Agency, Washington, D. C., ARPA Order No. 774, and administered by the Night Vision Laboratory of the U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, under Contract No. DA-44-009-AMC-1494(T).

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FORT BELVOIR, VA. 22060

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FOREWORD

This report was prepared by the Infrared Physics Laboratory of Willow Run Laboratories, a unit of The University of Michigan's Institute of Science and Technology. It is the first interim technical report submitted under Contract DA-44-009-AMC-1494(T), "Night Vision Aids for Counterinsurgency." The contract is funded by the Advanced Research Projects Agency, Washington, D. C., as part of Project AGILE; the ARPA-AGILE project monitor is Lt. Col. E. I. Golding, USAF. The contract is being administered by the Night Vision Laboratory of the U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

The objective of the contract is research and evaluation that will enhance the use of night vision aids by counterinsurgent forces. The program emphasizes improving the ability to predict the performance of a night-viewing system by measuring various contributing factors such as the viewing device, operator performance, and environment (target, background, and illumination).

ABSTRACT

The first year's effort was devoted primarily to a measured buildup of staff and accumulation of background information for use in the continuing program. A library of technical reports was assembled and catalogued. Target and background data were assembled and reviewed for application to the problems of night vision. Also collected were data concerning the characteristics of illumination from the night sky. Investigation of the ability to predict target visibility from these data was initiated.

Currently, plans for field evaluation of the EYEGLASS and Wide Field of View Starlight Scope (WFOV) devices are being prepared; preliminary field experiments with EYEGLASS are underway. As part of an investigation of visual differences among people in different parts of the world, a subcontract is being negotiated with the American University of Beirut (AUB) for a survey of visual acuity and dark adaptation among their students. Relationships among the various means of measuring acuity are being investigated in order to select the technique(s) most useful in predicting night-viewing performance under real-world conditions. An experimental color-viewing device that operates at low light levels is also being investigated.

Plans for the coming year include completion of the preliminary field measurements on EYEGLASS and WFOV and initiation of the evaluative tests by ARPA, active work on the AUB subcontract and a related measurement program at WRL, field work to develop relationships between field performances and measured characteristics, and experimental work with the color-viewing device. The primary objective of the program will continue to be the development of improved capability to calculate night-viewing system performance from measurements of system components and the target environment.

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1
WORK STATEMENT

The following work statement, quoted directly from the contract, is included as a general frame of reference for the rest of the report. The three sections that immediately succeed it are subdivided according to the three major tasks detailed in the work statement. The fourth task, entirely unrelated to night vision research, is being handled by the Radar and Optics Laboratory of Willow Run Laboratories (WRL) and will be reported upon independently by that laboratory.

ARTICLE I - SCOPE OF WORK. The Contractor shall furnish over a three (3) year performance period all engineering, labor, tools, equipment, materials, supplies, facilities and services necessary (except that to be furnished by the Government as hereinafter provided) and expand a level of effort and operate a center to conduct research and evaluation activities related to the enhancement of Night Aids for counter-insurgent ground forces. The objective of this effort is to enhance the Night Vision Capabilities of COIN combat personnel and shall include the following tasks:

TASK I

Information Acquisition and Problem Definition. The contractor shall collect, collate and integrate aggregate information on past and present technical programs which are sponsoring studies and/or developments of surface night aids. The contractor shall also collect, collate and integrate information on activities of COIN combat personnel with special emphasis being placed on friendly foreign indigenous forces.

The desired output of this task is twofold. First, it is intended to determine courses of action which can be readily implemented and which will enhance the surface night vision capability of foreign, friendly, indigenous troops involved in COIN operations. Secondly, it is intended to recommend means for expediting the introduction of improvements into concepts and to recommend appropriate configurations for operational use.

Emphasis will be placed on determining the state-of-the-art of night vision aids, their use in an operational mode, and the pertinent human factors involved in the use of such aids.

1.1 Target/Background/Illumination

Target/Background data collection and collation from available sources is to continue. This is not to be an experimental effort per se, but field measurements are to be accomplished as required. A major source of data should be the Target-Signature Library at The University of Michigan, Willow Run Labo-

ratories. Likewise, natural illumination data should be assembled, including the reflectance data published by the Institute of Defense Analyses and the Air Force Avionics Laboratory.

1.1.1 Model Calculations

Data from Task 1.1 can be used in the calculation of target brightness, contrast, and spectral characteristics. This subtask is to support the calculation of the nighttime values of such parameters for various situations (i.e., models) followed by measurement of their actual characteristics. This work is to provide an eventual ability to calculate the input to a model for use in system evaluations.

1.1.2 Trade-Offs Analysis

Many factors have to be weighed in selecting a vision aid technique for use in a given situation. This subtask is to provide for an analysis, with supporting measurements as required of the relative advantages and disadvantages of the various spectral regions, fields of view, resolutions, sensitivities and methods of illumination which affect the detection at night of people-size targets.

1.2 Colloquia and Technical Meetings

The planning and administration of human factors colloquia with respect to night vision aids, recce display, etc., is to continue. This subtask is intended to support also working group meetings of parties involved in human factors research to encourage the establishment of some standardization of experimental measurements.

TASK II

Experimental and Technological Assessment. The contractor shall perform research applicable to and shall assess those factors which affect the enhancement of COIN surface night vision. The contractor shall delineate limiting variables in device development, such as:

- a. Human performance in the use of operational equipments;
- b. The rate of translation of theoretical concepts into practical hardware considerations;
- c. The rate of technological advance in equipment design.

When limiting variables are delineated, appropriate studies and experiments will be performed by the contractor's research staff so that recommendations for remedial action can be substantiated. Subject to the approval of COR, remedial action effort may be performed by the contractor's research staff or by sub-contract to another research establishment under the monitorship of the contractor.

The desired output of this task is twofold. First, it is intended to "pinpoint" those long lead-time device components which would permit a significant improvement over the current state-of-the-art night vision enhancement devices. Secondly, it is intended to "pinpoint" the critical interface between a human and a device so that optimal design criteria for devices to be used by friendly foreign indigenous counterinsurgent ground forces may be specified.

2.1 Human Visual Process

In-house studies are to be a continuing activity with emphasis on visibility as a function of illumination, contrast, size and shape of targets, background, etc. For the remainder of FY-67 the following subtasks are to be initiated.

2.1.1 Study and Investigation of Relationships of Various Measurement of Visual Acuity. Using optotypes (i.e., test objects) which distinguish one acuity test from another, the following aspects of acuity tests should be investigated.

- a. Inter-relationships, i.e., taking each test on face value as a measure of comparative ability to see a particular optotype from a set of given optotypes.
- b. Comparative utility, i.e., taking each test to determine its usefulness to a designer of night vision aids in the sense of matching predictable instruments outputs, and as a measure of ability to see objects common to the night vision problems of COIN (i.e., stationary and fleeting targets).

At a minimum, the optotypes to be considered should include the Snellen "E", disks, the Landolt "C", bar patterns and spatial sine-wave patterns. Other optotypes may be considered such as those used in the U. S. Army Night Vision Tester, or any uniquely foreign optotype which may have been used to acquire a similar data base of man's acuity characteristics.

The investigation of inter-relationships and comparative utilities should be for daytime as well as night-time light levels, from moonlight down to starlight, and for optotypes which have variable as well as 100% contrast. Other factors to be considered should include the influence of adaptation, observation time, and true spectral character of the light. This work should be consistent with previous government supported experiments, particularly those supported at the Army's Night Vision Laboratory.

Finally, emphasis should be given to the reliability of acuity tests and the interactions between reliability, optotypes and test procedures. Products from this subtask should include:

- a. Data Base. To include the acquisition and evaluation of data from past tests. It should constitute a data base not only for U. S. nationals, but possibly for foreign nationals as well. Any gaps in data or the need of additional tests to fill these gaps should be noted.
- b. Recommendations for Flexibility in Testing. Using existing data from different tests on the same population (or statistically equivalent populations), inter-relationships between tests and test data should be established. Assuming that the relationships are invariant from one population to another, any of the tests might be suitable for use on new populations (i.e., foreign subjects) and the results cast into a-y of the other available forms. The feasibility of flexibility in testing is to be illuminated in this product.

2.1.2 American University of Beirut (AUB) Investigation

This subtask is to deal with the vision acuity measurements and testing of Middle East subjects as proposed by N. H. Haddad, M.D. of the American University of Beirut, Beirut, Lebanon, described in Contract DA-44-009-AMC-1494(T), Night Vision Aids for Counterinsurgency: Supplement to Program Planning Document, dated November 1966.

2.1.3 University of Michigan Program to Complement AUB Work

A parallel program to that of Task 2.1.2 is to be implemented in the United States. The purpose of this subtask should be to develop similar data for comparison with Dr. Hagdad's as well as with other acuity data on U. S. nationals.

2.1.4 Vision Survey Program (Thailand, etc.)

This effort is to be directed toward defining suitable tests for surveying the visual characteristics of foreign nationals in general, and explaining how such tests would be implemented in Thailand in particular.

The basic purpose of such surveys should be to ascertain whether the visual abilities of foreign nationals so differ from our own that the difference would have to be reflected in the night vision aids they might use. For telescope type aids (scotopic vision) where the key design variable is magnification the parameters to be compared are the visual acuities at given nighttime light levels. For image intensifier type aids (photopic vision) both magnification and output luminance are key design variables so that two comparisons are needed.

Since a qualified Thai organization or individual willing to undertake the task of survey testing is not known at this time, the basic purpose of this task is to determine just who is to do such testing, to obtain permission from the Thai Government for testing (of their military personnel), and to specify the test. Also involved is the selection of the apparatus to be used, and possibly, training of the personnel who would conduct the test.

2.1.5 Establishment of Criteria to Separate Differences in Visual Acuity from Differences in Image Perception

As a part of these tasks, criteria will be established, and experiments carried out if necessary to separate any differences in visual acuity from differences in image perception, among the various foreign groups.

2.2 New Night Vision Aids

2.2.1 In-house R&D

Emphasis in the immediate program is on the understanding of the visual process, systems evaluation and performance prediction within a parametric framework. It has been recognized, however, that R&D efforts might evolve to contribute new device design knowledge. The following subtask is to support this objective.

2.2.1.1 Color-Viewing Techniques and Applications for Image Intensifier.

It has been pointed out by Morton that an image intensifier could be used to view scenes in true color by the relatively simple expedient of using two synchronized rotating filterwheels, each having three primary color segments [1]. One filter would be placed at the entrance to the intensifier and the other would be between the image on the phosphor and the viewer. If the wheel is rotated at about 30 cps or more, the colors will merge and a colored image is seen by the viewer. The purpose of this task is (a) to investigate the usefulness of this technique to enhance target recognition and detection at low and intermediate light levels through the use of color; and (b) to investigate the feasibility of using this technique to translate the received spectrum to one which emphasizes certain desired characteristics. This applies to such problems as camouflage detection, etc.

A simple laboratory evaluation in conjunction with a theoretical study should be carried out first to establish the workability of the technique. If this appears promising, experimental models should be built for laboratory and field experiments, subject to Director, Project AGILE approval.

TASK II:

Evaluation Methodology. The Contractor shall evaluate current methods and procedures for determining the performance effectiveness of night vision enhancement devices. By means of analyses supplemented, if necessary, with experimentation, a generalized measurement method of determining performance effectiveness shall be devised.

The output of this task is intended to be a method of measurement and a procedure for stating the resultant values and criteria which would be applicable generally to the development and design of night vision enhancement devices.

In connection with and as a part of the above work and services, the Contractor shall furnish Data in accordance with DD Form 1423, Contractor Data Requirements List, plus attachments, marked Exhibit "A", attached hereto and made a part hereof.

3.1 Study and Investigation

The objective of effort under Task 3 is to be able eventually to describe and predict, parametrically, the field performance of an aid given its laboratory performance data.

3.1.1 Theoretical and Experimental Systems Analysis

The objective of this subtask is twofold. First, it is to develop a general quantitative method for evaluating night vision systems, including the target with its environment and the visual aid when used by a human observer. Whenever possible, this evaluation should be performed with limited field experiments. Overall system performance should be calculated based on the assumed Target/Background characteristics (Task 1.1), knowledge of the visual process (Task 2.1), and the measured characteristics of a visual aid resulting from initial studies supporting this task. Secondly, this task is to determine (a) the relationship between a test chart data and real target visibility; and (b) the effect of such factors as field of view and line of sight on scanning functions. In resolving information as required for this task, suitable laboratory measurements and field measurements should be performed on G.F.E. night vision aids to document their characteristics. Also, these measurements should be sufficiently complete to define accurately the performance data under a variety of conditions. Effort should be made to include many typical problems of detection, recognition and search using targets and backgrounds similar to those encountered in guerrilla warfare.

3.1.2 Information Extraction from Displays

The objective of this subtask is twofold. First, it is to determine how man makes use of displayed information, and from this to determine the best means of displaying surveillance imagery. Typical variables to be investigated are:

- a. Data assimilation rate.
- b. Detection rate, and
- c. Recognition rate for

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1. Continuously moving strip presentation vs. a series of stationary frames,
2. Supplemental reduced resolution, peripheral displays vs. no supplemental displays, and
3. Moving targets vs. static targets with and without noise.

Secondly, it is to develop plans for conducting human factors experiments and simulation during FY-68 to determine the expected probability of detection of targets in specified SLR (Side Looking Radar) imagery. These experiments will be designed in conjunction with test results expected from the Air Force Flight Test (FY-68) with the ARPA/AGILE DANCING DOLLS radar system configuration.

3.2 Evaluation Experiments

The purpose of this task is to prepare plans for overseas testing and detailed CONUS evaluation of two specific experimental night vision (G.F.E.) aids — EYE GLASS and Modified Wide Field of View Starlight Scopes. With respect to plans for testing EYE GLASS, emphasis is to be placed on the structuring of tests to determine optimal operational profiles for using the aid as well as for analyzing the performance of a man with the aid, without the aid, or with a simpler and/or better known aid. Pilot field measurements, if necessary, are to be carried out in the vicinity of the Willow Run Laboratories using both test targets that have been surveyed into position and targets which more nearly resemble operational targets. In some instances, it may be necessary to perform pilot tests at more remote locations where target/backgrounds are available, (i.e., Eglin Air Force Base). It is anticipated that CONUS airborne tests may be required to evaluate EYE GLASS. If an aircraft is required, a G.F.E. aircraft will be made available for use, if possible. If not, required tests will be conducted with a rented C-47 where aircraft and suitable targets can be made available. Detectability of chart-type targets should be determined both with and without electronic stabilization and also using some other simpler aid, if possible. Similar measurements of detectability of typical realistic targets will be measured. During any airborne measurements, there will be particular attention to the human operator's performance. Problems such as fatigue, vertigo, loss of orientation, motion sickness and ability to scan is to be documented.

An evaluation report will be required along with the test plan to describe the work which was done, present the conclusions and make any recommendations which may result from pilot tests and observations.

With respect to plans to test and evaluate the Wide Angle Image Intensifier Units, both technical and typical "real" target/backgrounds should be considered for use. Tests should be designed for execution in the vicinity of Willow Run Laboratories initially and continued elsewhere if necessary to obtain the desired variety of targets and backgrounds. Attention is to be focused on the trade-off between field of view and resolution for various aim and searching activities. Pilot test plans will be submitted to Director, Project AGILE for approval prior to execution.

TASK IV

The Contractor shall conduct a technical study and evaluation of "Dancing Dolls" in the following objective:

- a. The evaluation of the scientific data on which the proposed reconnaissance system is based.

- b. The determination of the likelihood of success or failure of the proposed system to attain its system objectives.
- c. The generation of recommendations based on a. and b. above of what the technical objectives of the program should be, given the present state-of-the-art equipment, and
- d. The identification of a test and evaluation program of the system in order to determine what meaningful capabilities the system has or does not have.

2

REPORT OF THE FIRST YEAR

The past year has seen a measured and orderly growth, limited in rate by deliberate recruitment of scientists and by the funding level. By the end of the reporting period the scientific staff was nearly at the proposed level, the equivalent of ten full-time scientists, while the technical support staff was considerably below the anticipated level of ten men.

In keeping with the program plan, the major effort during this period has been devoted to gathering of data and information, a survey of the state of the art, and general familiarization with current night-viewing devices and their use. There has also been an effort to obtain an understanding of the night-viewing problem for the military user of night-viewing devices.

2.1. TASK I: INFORMATION ACQUISITION AND PROBLEM DEFINITION

This task involves data collection, a search and review of the literature, organization of and participation in meetings, and familiarization with the state of the art and with the military's night-viewing problem.

Much of this work, while important, is considered supportive and does not in itself constitute research.

Immediately upon initiation of the contract, a review of the literature was begun and a library of technical reports on night vision and night vision devices established. Most of the approximately 200 reports in the library have been filed, cross-indexed, and annotated, largely for use by the scientific staff. The library is available to others doing similar or related work, but no specific effort has been expended to make the material known or useful to personnel outside WRL.

Most reports and meetings have been technical in nature, concerned with developing night-viewing devices and understanding human vision under low light conditions. To obtain more information about, or at least a better feeling for, the night operations problem itself, two of

our personnel spent a day discussing night operations experiences, with and without night vision aids, with personnel at the John F. Kennedy Center for Special Warfare at Fort Bragg, North Carolina. We did not attempt to establish any specific facts, but rather tried to provide a general background for ourselves regarding night operations as seen by the actual user of night vision aids. The personnel with whom we spoke had recently returned from active experience in Vietnam.

WRL Personnel have attended symposia at the Institute for Defense Analyses where night vision aids and their uses by all three services were discussed.

Reports of military use and evaluation of night vision aids have been obtained and are included in the above mentioned library.

Another activity in the category of general information acquisition was the organization and administration, at ARPA's request, of a colloquium entitled "Human Factors Aspects of Real-Time Night Airborne Reconnaissance." Papers describing experimental work related to this subject were presented by a number of representatives of industrial organizations presently working in the general area of reconnaissance systems. The meeting was held during January 1967, at the Institute for Defense Analyses. The proceedings are being published as a supplement to the CIRADS proceedings [2].

In addition to information for general familiarization and reference, there has been an effort to acquire, and to some extent review, target and background measurement data, including detailed data, such as the reflectivity of leaves, cloth, etc., and broader data, such as the characteristics of a forest or a plowed field. Sources of these data are listed in bibliographical form in the appendix. Similarly, available data concerning night illumination have been acquired and reviewed; a summary of this review is presented in section 5. Our purpose is to use these or similar data to calculate target contrast, brightness, etc. when viewed under specified conditions with a viewing device having known spectral and sensitivity characteristics. Some work has been done toward replotting and/or retabulating data in a form more suitable for use in system performance calculation.

2.2. TASK II: EXPERIMENTATION AND TECHNOLOGICAL ASSESSMENT

The study and measurement of human vision and the interpretation and use of such measurement is a major objective of this program and particularly of this task. A better understanding of the human operator and an intelligent use of this improved understanding are vital to the design of improved night vision aids and reliable prediction of their performance.

During this first year, a general review was made of work relating to measurement and interpretation of human visual characteristics; section 6 is an outcome of this review.

Another, immediate objective is to relate performance measurements made with the several commonly used optotypes, including bar charts, sinusoidally modulated bar charts, the Landolt C, the Snellen E, discs, and various special-purpose forms.

The ultimate objective is, of course, to establish a relationship between acuity measured in the laboratory and perception of real targets in a real environment. This is a necessary step toward the prediction of system performance.

To date, the WRL program has been concerned with gathering visual performance data obtained by the various techniques in order to gain an understanding of these techniques and their limitations. The immediate objective is to select a small number of test procedures that yield data of most value to systems performance prediction and that can be readily administered to subjects in our laboratory as well as in overseas environments.

Since this project is concerned with counterinsurgency and aid to foreign indigenous forces, we feel it pertinent to examine differences between U. S. nationals for whom military night vision aids have been designed and about whom we have the most data and the indigenous personnel whom we wish to assist. There may or may not be differences of sufficient magnitude and importance to require somewhat different visual aids or different instruction in their use. Differences in acuity could be due to environment (bright sun on the desert, for example), dietary differences, or ethnic differences. It is also possible that perception could be influenced by a subject's experiences and living conditions (one does not perceive targets with which he is unfamiliar in the same manner he does those with which he is very familiar).

As a small first step in investigating this problem, The University of Michigan began negotiations with the American University of Beirut (AUB) to establish a program of visual measurement there under the guidance of Dr. Nadim Haddad, an ophthalmologist of their medical faculty. Acuity and dark-adaptation measurements will be made on a number of AUB students for whom rather good medical and historical data are available. Appropriate physiological data will also be recorded at the time of testing. Representatives of several races and backgrounds will be available. The data will be analyzed for any indication of significant differences from equivalent data obtained elsewhere (e.g., within the continental United States).

This program was discussed with Dr. Haddad during his recent visit to the United States and specifications for a set of visual tests prepared. A modified Bausch & Lomb Orthorater to be used in the testing was procured and work begun on its modification for use in low light levels. Also, a set of slides comprised of Landolt C rings of varying size and contrast was prepared.

2.3. TASK III: EVALUATION METHODOLOGY

This task includes all work relating to equipment evaluation. All experimental or test work with operational equipment is considered to come within this task.

Initial work consisted of making a series of rather elementary measurements of the acuity of an operator using the Starlight Scope (the only image-intensification viewing aid available to us), a pair of 7 x 50 binoculars, and a higher power, wider aperture telescope built for night viewing. This was done primarily to familiarize our staff with the image-intensification device and to obtain some contact with the problems of conducting reliable field measurements at night.

At ARPA's request all work early in the program was confined to ground-to-ground problems. Within the last few months work has been extended to include airborne, direct-imaging intensification devices but still does not include low light level TV.

We were requested by ARPA to prepare recommendations for tests to be conducted by ARPA outside the continental United States that will evaluate EYEGLASS and the Wide Field of View Starlight Scope (WFOV). This is a major effort involving both field and laboratory tests at WRL as well as actually preparing test plans. Visits were made to the Army's Night Vision Laboratory (NVL) and Electro Optical Systems Inc. (EOS), the developing company, to discuss both devices.

Because it is more complex, has an earlier delivery date, and, being airborne, poses much more severe testing and evaluation problems, the greatest effort has been devoted to the EYEGLASS program. The first and second phases of technical tests of EYEGLASS were discussed at NVL and EOS and at Eglin Field where they were performed. It was concluded that while the tests had demonstrated successful operation of EYEGLASS, a further set of tests should be made, with more complete instrumentation and better control of the target complex and the flight profile. Section 7 discusses the program to evaluate both the EYEGLASS and WFOV devices.

3

PRESENT STATUS

The scientific staff is now approximately equivalent to nine full-time scientists. The goal being ten, this staff is very nearly complete unless there are changes in the level of effort and funding. The technical support staff is still undermanned because there has been little or no work for them until rather recently. To carry out evaluation and measurement, it is now necessary to increase this staff from two to four or five.

3.1. TASK I: INFORMATION ACQUISITION AND PROBLEM DEFINITION

No specific effort is being expended to further build up the library of pertinent technical reports and the file of information on R & D relating to night vision, night operations, vision aids, etc. All continuing work of this nature is being done as part of whichever task is relevant.

Photometric instrumentation has been set up to validate some of the data mentioned in section 5 and the appendix and to make irradiance and radiance measurements for the evaluative work of task III.

3.2. TASK II: EXPERIMENTATION AND TECHNOLOGICAL ASSESSMENT

Formal discussions with AUB regarding the subcontract for the vision survey to be carried out by Dr. Haddad are continuing.

A very simple, experimental, rotating filter-wheel system to be used with an intensifier tube in some preliminary color-viewing and spectral translation experiments is nearly complete. Image tubes having S-1 and S-20 photocathodes have been procured for the system.

3.3. TASK III: EVALUATION METHODOLOGY

The planning of evaluative tests of the EYEGLASS and WFOV devices and related experimentation is presently being emphasized (see sec. 7). The first phase of the experimental work with the two EYEGLASS units that have been received is under way. WRL's C-47 aircraft is carrying the EYEGLASS device. The radar to be used to track the C-47 and maintain the target normal to the line of sight has been checked out and is now set up at the test site near Ann Arbor.

The WFOV units have not been received yet but are supposed to arrive by mid-June.

4

PLANS FOR THE SECOND YEAR

4.1. TASK I: INFORMATION ACQUISITION AND PROBLEM DEFINITION

At ARPA's request, general information gathering and the library will receive only minimal attention. Work of this nature will continue to be restricted to subjects directly related to specific tasks and performed as part of those tasks.

There will be a continuing effort to assemble available data from measurements of target and background characteristics and the spectral irradiance of the night sky. In general, this will not be a measurement program, although it is anticipated that measurements may be made

to validate some data or to confirm the results of calculated contrasts for specific combinations of targets, backgrounds, illuminating spectra, and sensory spectral curves.

The primary objective of this work will be the calculation of image contrast and brightness for given vision aids and input conditions. From this work it should also be possible to study trade-offs among the many factors that must be considered in designing a vision aid system and ultimately to select the optimal design parameters for a given application.

4.2. TASK II: EXPERIMENTATION AND TECHNOLOGICAL ASSESSMENT

The AUB subcontract for carrying out a vision survey using the AUB population as subjects should be let shortly. Concurrently, at WRL a similar set of measurements will be made, partially as a control on the AUB measurements, but also to aid in evolving better, simpler test procedures suitable for further survey work. This program is expected to include the development of more suitable optotypes or at least a better means for their fabrication. Also, test procedures that can be reliably and efficiently used despite a severe language barrier and/or poorly educated subjects will be investigated.

The initial work of this nature has dealt almost entirely with very conventional laboratory measurements of visibility as a function of light level, size, contrast, etc. As this work progresses, recognition of targets against a background (perception) will become the primary interest. It is hoped that relationships can be shown between some of the conventional acuity measurements and perception, at least for limited, quite specific conditions. Whether or not such relationships can be established, there will be an attempt to develop readily performed measurements that do yield a reliable measure of the perception of an individual or a system. At some later date measurements of this sort should be incorporated into the AUB work.

The experimental filter-wheel system will be used with the S-1 and S-20 image tubes in some preliminary experiments. The filter material now on hand will yield more or less true-color results with the S-20 tube. To use the S-1 tube with its near-infrared response, a set of filters that have rejection bands extending into the near infrared will have to be obtained. As soon as this is done, experiments will be performed concerning the possible use of spectral translation effects to enhance specific target characteristics. In particular, the ability to discriminate between true foliage and various kinds of camouflage will be investigated.

Color Presentation and Spectral Translation. The image intensifier is, inherently, a monochromatic viewing device. The input spectral sensitivity is that of the photocathode (usually an S-20), and the output is produced by intensity modulation of a phosphor. Several years ago it was pointed out by Morton that, in principle, one could simply use two color wheels

to change input and viewing filters sequentially to produce a field-sequential system that could provide reasonably true-color images [1].

Clearly, such a system would be less sensitive because of the attenuation of the filters and the energy loss caused by the decreased spectral bandwidth. This disadvantage might be more than compensated for by the increased ability to recognize targets shown in color, at least at intermediate light levels where some energy loss can be tolerated.

Color viewing in itself is an attractive thought and one that we feel should be investigated. One can, however, consider the additional flexibility that the combination of intensifier and color wheel affords. Since the viewing filters need not correspond to the input filters, one can establish any arbitrary relationship. Thus, colors may be transposed, or a set of very closely spaced narrowband input filters can be used with the corresponding viewing (output) filters spaced to cover the visible spectrum, expanding, in effect, one small portion of the object's spectrum to cover the entire visible spectrum. This could make very small color (spectral) differences visible, including those outside the visible spectrum yet within the spectral response of the photocathode. An application of this system that comes immediately to mind is the real-time detection of camouflage; the special color film currently used must be processed after a reconnaissance mission. Another application is the tagging of equipment and/or personnel with minute quantities of dye.

The present program includes fabrication of a very simple laboratory model of such a system that uses a commercially available image tube. A second tube having a different photocathode has been borrowed from NASA. That neither tube has the correct phosphor spectral characteristic or decay rate may be a serious limiting factor; however, some simple evaluative experiments can be performed.

4.3. TASK III: EVALUATION METHODOLOGY

A major portion of the effort at WRL will be applied to this task in accordance with recent discussions with the ARPA contract monitor in which the primary objective of the program was established to be improvement of the ability to predict overall system performance on the basis of laboratory data plus limited field measurements. Such system performance prediction would permit evaluation of new devices or systems without recourse to extensive field trials and as an ultimate goal, would make it possible to adequately evaluate aids at the design stage as soon as the basic performance characteristics could be stated.

The immediate work will continue to be directly related to the formulation of test plans for the evaluation by ARPA of the EYEGLASS and WFOV (sec. 7). From field and laboratory

measurements of EYEGLOSS and WFOV made at WRL, we expect to obtain some quite reliable system performance data. Other night vision aids have been requested through ARPA, and as they become available, similar measurements will be made. The result should be a consistent set of data that includes both laboratory acuity measurements and field performance against various optotypes and combinations of real-world targets and backgrounds.

Analysis of these data should result in checks on the validity of presently used models and hopefully, in improvement where they do not appear to adequately describe the observed system performance. This is acknowledged to be a very empirical approach, much less satisfying scientifically than a completely descriptive mathematical model. The empirical model will, however, be available much sooner and may be entirely adequate if its limitations are recognized.

The test site mentioned in section 3.4 is readily accessible, yet remote enough from any concentration of habitation that light levels are determined almost entirely by natural illumination. The land is owned and controlled by the University. Work at this site has just begun, but if it is as successful as anticipated, we believe it should be continued. In particular, it is likely that the EYEGLOSS should be operated with an aircraft other than the C-47, probably with a UH-1 helicopter. This would yield data useful for comparison with the C-47 data and also as basic EYEGLOSS performance data.

5 NIGHT ILLUMINATION

In order to study intelligently night vision aids, one must know the illumination to be expected under those conditions during which night vision is used.

The illumination conditions of concern to this program are the spectral irradiance produced at the ground by the sky, its directionality, spectral distribution, and any other properties that affect the radiance of a target and its background. It is apparent from the literature that systematic investigations to determine such illumination conditions at night are not numerous, and the few existing investigations are almost entirely limited to the visual region. On the other hand, there have been many observations of night sky radiance for several other purposes. Astronomical studies and studies of airglow and aurorae have produced volumes of data on sky radiance. These data have been used to estimate spectral irradiance levels for clear, moonless skies when such phenomena are observable. Surprisingly, less information is available about the illumination produced by the moon; however, sufficient information has been gathered and combined with the known characteristics of daylight to produce estimates of moonlight illumina-

tion. Thus, realistic estimates of clear sky illumination can be obtained. The effect of overcast on night illumination has been treated in much less detail, and it is possible at present to provide only uncorroborated estimates of illumination under overcast conditions.

Up to the present we have done no new work in this field but rather have collected what appear to be the best and latest data from which we have derived average levels of night spectral irradiance for two ideal conditions, a moonless, clear night and a night illuminated by the full moon. Consideration is given to the deviations from these average levels that might be expected under similar real conditions insofar as data are available. Lastly, the effect of overcast skies on the illumination levels is considered. It is in this area that the greatest amount of uncertainty lies because actual measurements are lacking and because overcast conditions can vary greatly.

Several summaries of night illumination and sky radiation have been published, each emphasizing different facets of the subject [3, 4, 5]. To avoid repetition, we utilize the results of these three references, adding material from other references to provide an overall summary of night illumination. It will be apparent in the following sections that much information is lacking about illumination levels. For instance, although limits can generally be placed on illumination levels on overcast nights, completely reliable prediction of such levels based on cloud cover data appears to be impossible at present.

Because moonlight, when present, completely overpowers other sources of night illumination in the visible region, a separation of night illumination into two categories is usually made: (1) all sources of illumination save moonlight and (2) moonlight. It is also helpful to divide illumination conditions into (1) clear sky and (2) overcast conditions.

5.1. SOURCES OF ILLUMINATION OTHER THAN MOONLIGHT*

Mitra [6] summarizes sky luminance in the visual region on clear, moonless nights as being composed of

Starlight, direct and scattered by our atmosphere: 30%

Zodiacal light (sunlight scattered by interplanetary dust): 15%

Galactic light (starlight scattered by galactic dust): 5%

Nightglow: 40%

Light from previous three scattered by our atmosphere: 10%

*Although aurorae are interesting and occur frequently at high latitude, producing significant illumination, their occurrence is considered too unreliable to be depended upon as an illumination source; they are therefore ignored in this study.

Figure 1 shows the estimated, approximate spectral radiance of a clear, moonless night sky as a function of wavelength from 0.4 to 2.2 μ , constructed on the basis of information gleaned from references 7, 8, and 9. This spectrum produces a luminance of 3.6×10^{-8} lm-cm⁻²-sr⁻¹ and includes the above listed components whose contributions are now summarized.

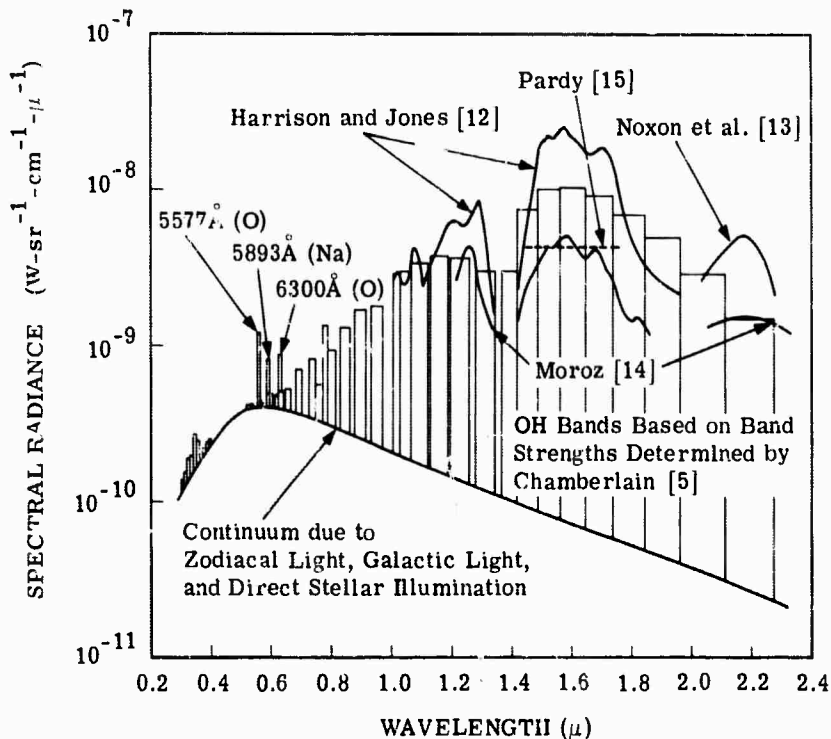


FIGURE 1. APPROXIMATE AVERAGE SPECTRAL RADIANCE OF THE NIGHT SKY AT THE ZENITH. No moon, clear. Luminance is 3.6×10^{-8} lm-cm⁻²-sr⁻¹. Luminous emittance is 1.1×10^{-7} lm/cm⁻² or 1.1×10^{-4} fL.

Night airglow, or nightglow as it is often called, is the diffuse optical radiation originating in our atmosphere. A large number of observations of nightglow have been made, and several authoritative summaries of the state-of-knowledge of nightglow are available [7, 8]. In the visible spectral region, nightglow is dominated by radiation from the 5577-Å oxygen line. This radiation produces between six and nine percent of the total visual illumination on a clear, moonless night [7]. Other important atomic lines of the night glow in the green and red portions of the spectrum are the weaker oxygen lines at 6300 and 6364 Å and the sodium doublet at 5890 and 5896 Å.

Another important feature of the nightglow is the green continuum between 4930 and 6000 Å, which is of uncertain origin. If it is made up of a large number of lines, these have not yet been resolved. Yet another feature of the nightglow is the ultraviolet and blue radiation, consisting largely of numerous closely spaced bands, many of which have been identified as Herzberg bands of O_2 . The dominant feature by far of the nightglow spectrum is the hydroxyl (OH) emission extending from the ultraviolet to 4.5 μ . Although relatively weak at the short wavelengths, OH emission becomes important at about 6000 Å and dominates the nightglow spectrum at longer wavelengths. The OH bands known to exist between 2.2 and 4.5 μ have not yet been observed because of the overpowering strength of the atmospheric thermal radiation beyond 2.2 μ .

The continuum radiation due to direct and scattered starlight and zodiacal light constitutes the remainder of the clear, moonless sky radiance.

Roach states that in the visual region the spectral zenith radiance of the night sky continuum, including starlight, zodiacal light, and the green airglow continuum, is on the average very close to the equivalent of 300 tenth magnitude stars per square degree of the spectral class G_0 (this class is typified by a temperature of about 6000°K) [9, 10]. The spectral radiance in the ultraviolet produced by such a quantity of stars agrees well with the observed continuum in this spectral region. At longer wavelengths, the OH emission appears to be great enough to mask the stellar contribution almost completely. Carpenter used a star count to determine the contribution of the direct stellar light to the visual continuum [5]. In principle it would be possible to perform a star count as a function of spectral class and, using the blackbody functions for the temperatures of these classes, to compute a total stellar irradiance spectrum [11, 12]. However, the available tables of star counts according to spectral class include only stars brighter than tenth magnitude, whereas Carpenter shows that only one third of the stellar illuminance (visual region) comes from these stars. Furthermore, as it is known that a majority or most of the dimmer stars belong to the cooler spectral classes [13], it is unrealistic to estimate the spectral irradiance of the total starlight on the basis of the spectral irradiance of the brighter stars. Thus, for lack of more reliable information, the continuum curve is taken to be the radiance produced by 300 tenth magnitude stars per square degree of spectral class G_0 (as shown on fig. 1). In the infrared the magnitude of this continuum is seen to be unimportant because of the overwhelming contribution of the OH bands.

The total radiant power in each of the lines and bands presented in figure 1 were taken from Roach [8]. For illustration purposes, the equivalent width of the emission from the oxygen and sodium lines were taken to be 100 Å, and the equivalent width of each OH band was taken as the spacing between its most widespread lines. (A table of OH line positions for each band is

is given in ref. 7.) Figure 1 thus presents our best estimate of the zenith spectral radiance. Also presented in this figure are values of the zenith spectral radiance measured by Harrison and Jones [14], Noxon et al. [15], and Moroz [16] as reported by Kruse [4]. A value reported by Pardy [17] is also shown. These measurements cover a range of about a factor of 5; the range is centered close to the spectrum determined from the band strengths given by Chamberlain. Since the measurements were made at various times and at various geographical locations, it is difficult to do more than speculate on the reasons for their disagreement (see sec. 5.2). No experimental results are shown at short wavelengths, since these measurements are very numerous and have already been used in the determination of the curve itself.

In order to determine illumination levels, it is also necessary to know how spectral radiance varies over the sky. Since it has been popular to attempt to estimate airglow height from radiance variation with zenith angle, information on the radiance variation with zenith angle is of course available for most airglow components. Chamberlain [7] indicates that the variation of the oxygen lines and sodium lines with zenith angle is approximately that shown in function a of figure 2. Function b of figure 2 is given by Chamberlain for the variation of the green continuum of the airglow (5300 Å) with zenith angle and includes the contribution from the starlight continuum. Shemansky and Jones indicate that at 1.5 μ the OH emission at a zenith angle of 80° is about four times the zenith radiance on a very clear night (minimum scattering) [18]. On this basis, function c, a curve similar in shape to those presented by Chamberlain, was constructed having this ratio of intensities at zenith angles of 0° and 80°.

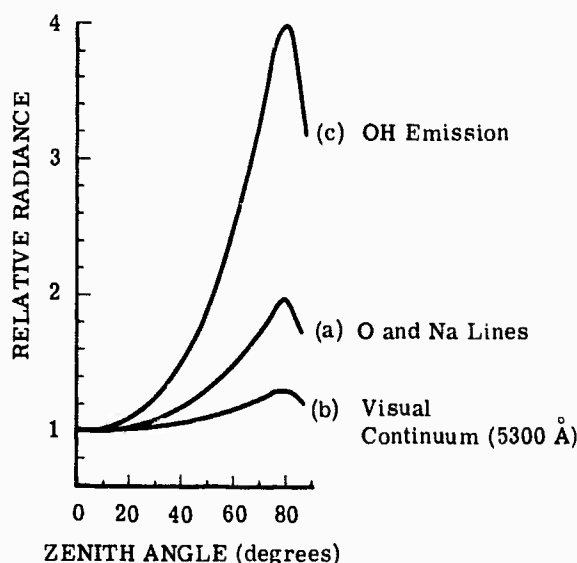


FIGURE 2. VARIATION OF RADIANCE WITH ZENITH ANGLE

By means of the curves of figure 2, the radiance of a moonless, clear night sky (fig. 1) was integrated over the total hemisphere to obtain figure 3. This figure is the best estimate we can give of the average total spectral irradiance incident upon a horizontal surface. The irradiance measurements made by Johnson et al. have been superimposed and appear to agree well at short wavelengths [19]. Beyond 1.2μ they diverge rather severely from our estimates. Measurements of the spectral irradiance at these wavelengths made by Morley indicate much lower values [20]. Again, these differences cannot be accounted for.

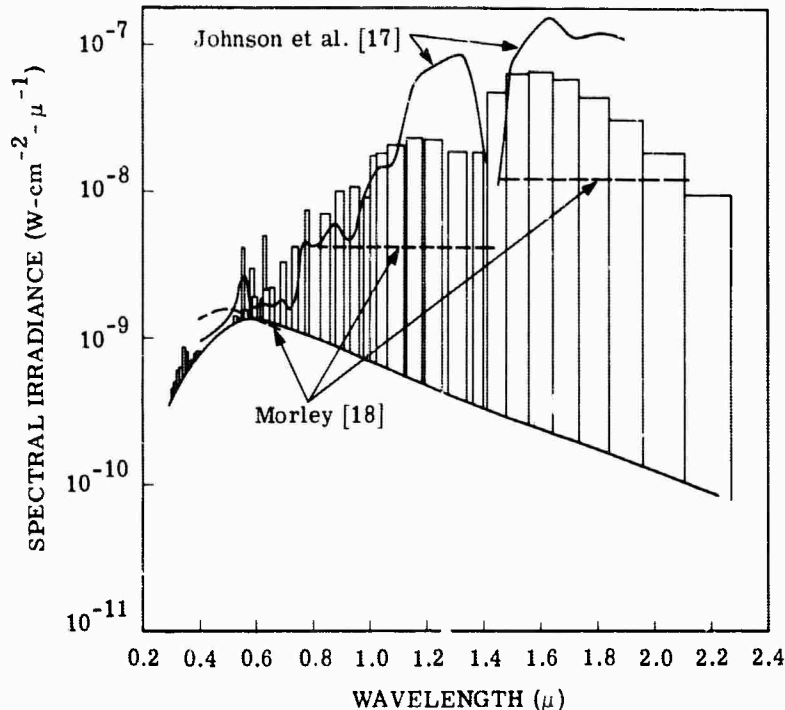


FIGURE 3. APPROXIMATE AVERAGE IRRADIANCE OF A HORIZONTAL SURFACE. No moon, clear. Illuminance is $1.2 \times 10^{-7} \text{ lm/cm}^2$ or $1.1 \times 10^{-4} \text{ fc}$.

5.2 VARIATIONS IN THE SPECTRAL IRRADIANCE ON CLEAR, MOONLESS NIGHTS

It is apparent from the experimental results plotted on figures 1 and 3 that the results of different observers at different locations can vary greatly (by as much as a factor of 15 in fig. 3), possibly because of

- (1) Differences in instrument calibration
- (2) Variations in illumination with geographical location
- (3) Variations in illumination with time at a fixed location

Although no evaluation of the quality of the experimental results in terms of their individual calibrations is possible here, it appears that there can be some divergence among the calibration techniques used by different observers, and hence large variations in their results might be expected. The calibration techniques of nightglow measurements often use an astronomical target (a star) as a standard against which the nightglow radiometer is calibrated. The problems that can be encountered when calibrating a radiance-measuring device with a distance point source, such as a star, are well known [20, 21]. Roach discusses a technique in which an absolute calibration is obtained by using the sky radiation at 5300 \AA as a standard [9]. In all fairness to the experimental data plotted in figures 1 and 3, it should be stated that wherever the calibration procedure was described, standard radiometric sources were used, and therefore it is not possible to attribute any deviation to calibration differences.

It appears that the information available on variation of illumination with latitude, time (i.e., longitude relative to the sun), and season is incomplete and sometimes contradictory. Chamberlain [7] discusses these variations in detail, and Roach [10] reports a series of later measurements showing the variations at 5200 \AA . It is apparent, however, from these two references that different components of the nightglow vary in different ways, although, with the exception of the $5577\text{-}\text{\AA}$ oxygen line and the sodium D lines, radiation from these components generally varies between $1/2$ and $1\ 1/2$ times the mean level of radiation. The work of Roach and Chamberlain does not explain the large differences among the measured values around $2\ \mu$ in figure 3; these differences remain unexplained.

5.3. EFFECTS OF CLOUDS AND OVERCAST ON THE ILLUMINATION OF MOONLESS NIGHTS

According to the results of Pardy [17] and Morley [20], on cloudy or overcast nights, even at relatively large distances ($\sim 10\text{ km}$), artificial lights affect the illumination level considerably because of reflection from the bottom of the clouds. Also because of the clouds, the relative reflectance of the ground surface can be expected to have a noticeable effect on the illumination. Morley indicates that, at a site at least 5 km from artificial lights and at least 15 km from Quebec City, the illumination in the visible region is generally greater on overcast nights than on clear nights; he attributes this solely to artificial lights. At the same site, however, the opposite effect is noted between 1.4 and $2.0\ \mu$, indicating that only minor contributions from artificial lights exist in this region. A third spectral region, 0.7 to $1.4\ \mu$, showed essentially no variation of illumination level with overcast. Pardy indicates that at a site near Christchurch, New Zealand, but whose exact proximity to artificial sources of illumination is unknown, variations in the zenith spectral radiance between 1.45 and $1.85\ \mu$ on cloudy or overcast nights can be greater than 2 orders of magnitude, again attributed largely to the presence of artificial

illumination. The available information concerning the effects of clouds and overcast can be summarized as follows: Although the presence of clouds and overcast can attenuate the illumination of the ground by the night sky by as much as a factor of 10, concentrations of artificial lights, even at relatively large distances from the point of interest (as much as 10 to 15 km), can increase the illumination in the visual region to a level comparable to or greater than that of a cloudless night. In addition, one would expect that in the presence of clouds or overcast, highly reflective ground coverings, such as snow, would further increase the illumination in the visible region.

5.4. MOONLIGHT AS A SOURCE OF NIGHT ILLUMINATION

When present, moonlight is the dominant source of night illumination and as such is very important. Less seems to have been written, however, about moonlight than about nightglow and other night sources of illumination. Some information is contained in reference 13, but the most detailed treatment of moonlight illumination is that of Biberman et al. [3], which incorporates the earlier work of Brown [22]. More information on the spectral distribution of moonlight is contained in a very recent work by Biberman and Celi [23].*

The spectral distribution of direct moonlight including losses due to absorption and scattering has been estimated in reference 23 for several lunar zenith angles (air masses). However, these estimates are not directly applicable to the total irradiance of a horizontal surface, since much of the light scattered from the direct beam is recovered as scattered illumination from the night sky. Figure 4 (taken from ref. 3) shows the illuminance of a horizontal surface ascribable to direct and scattered moonlight as a function of phase and lunar zenith angle. No specific information on the spectral distribution of the total lunar irradiance of a horizontal surface is available. However, two curves in reference 3 indicate that the spectral distribution of sunlight plus skylight is similar to that of exoatmospheric sunlight, and on this basis one might postulate that the spectral character of the total moonlight irradiance of a horizontal surface is similar to that for exoatmospheric moonlight. Figure 5 shows the

*The value given for the absolute level of lunar illumination varies according to the technique by which it is obtained. The differing values contained in references 3 (incorporating ref. 22), 13, and 23 demonstrate various inconsistencies: values are, for example, (1) given in the form of apparent visual magnitude [13]; (2) computed from a direct comparison of lunar and solar illumination levels [22]; and (3) computed from lunar reflectance, solar illumination, and geometric relationships [23]. The values given for direct illumination by a full moon at zenith range from 1.58×10^{-2} fc [23] to 2.96×10^{-2} fc, the apparent visual magnitude given in reference 13. The values for total illumination vary from 3.45×10^{-2} fc, based on experimental evidence of unknown origin [22], to 2.59×10^{-2} fc, computed by WRL using the solar illumination from reference 22 and the geometric factors of lunar reflectance quoted in reference 13.

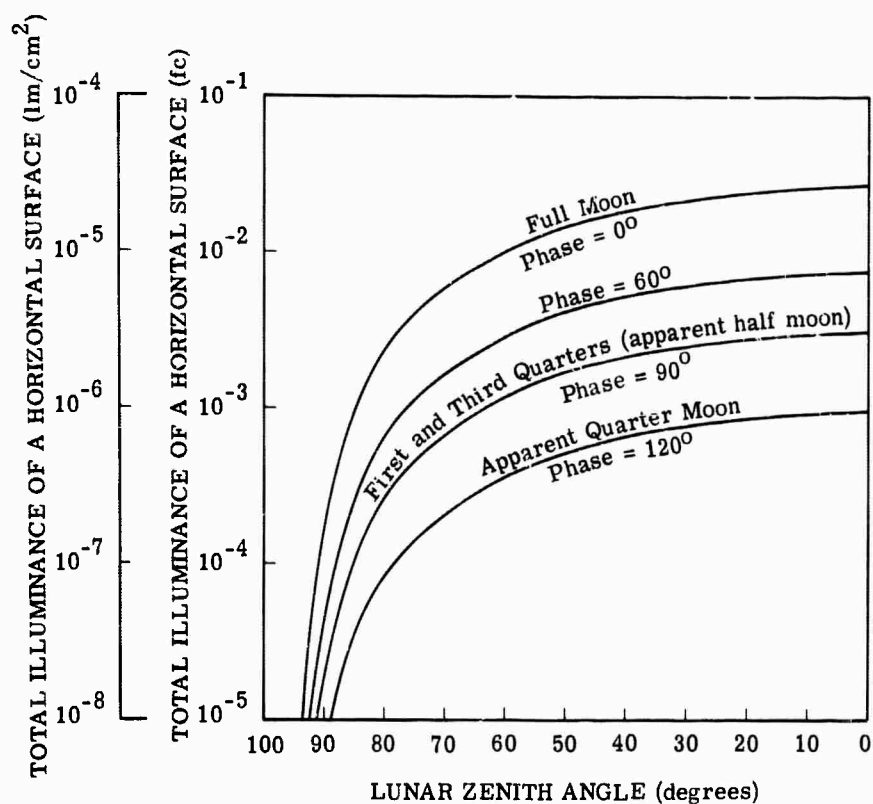


FIGURE 4. LUNAR ILLUMINANCE AS A FUNCTION OF LUNAR PHASE AND ZENITH ANGLE [3]

spectral irradiance of a horizontal surface from a full moon at a 60° zenith angle compared to the smoothed spectral irradiance from a clear, moonless sky (from fig. 3). The spectral shape of the lunar irradiance in figure 5 has been taken to be that for direct moonlight through an air mass of two (from ref. 21), even though the total (direct plus scattered) moonlight includes a relatively greater contribution at short wavelengths because of the recovery of a portion of the radiation scattered from the direct beam. The magnitude of this spectrum has been chosen to agree with figure 4. It is apparent from figure 5 that in the visual region out to about 1.4μ , moonlight is by far the most significant source of illumination. Beyond 1.4μ the irradiance from the OH emission of the night sky becomes greater than the irradiance from the moon.

5.5. EFFECTS OF CLOUDS, HAZE, AND OVERCAST ON MOONLIGHT ILLUMINATION

Almost nothing has been written about the effects of overcast on moonlight illumination. However, because (1) the sun and moon subtend approximately the same arc and (2) either,

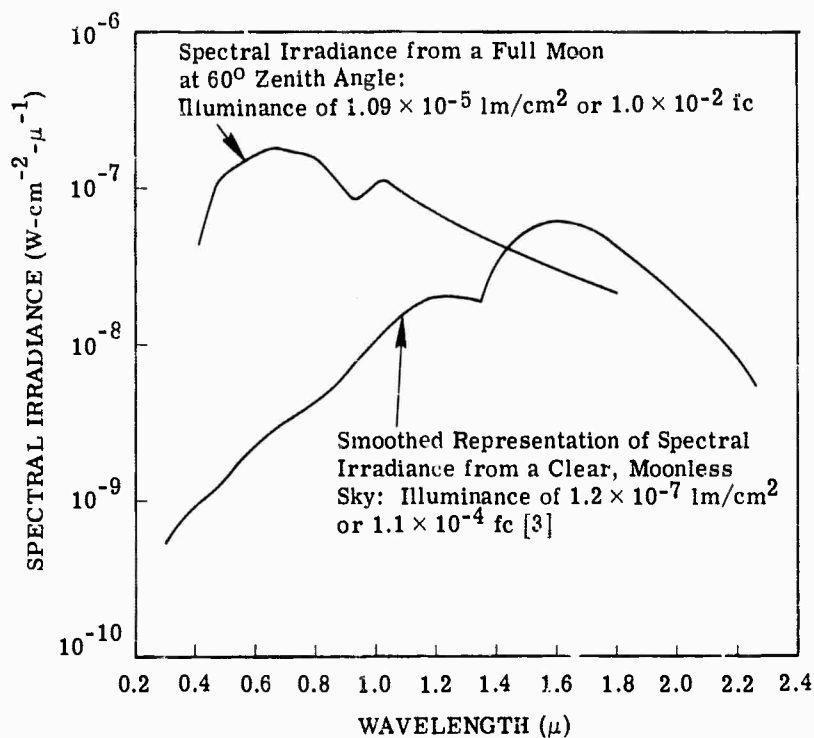
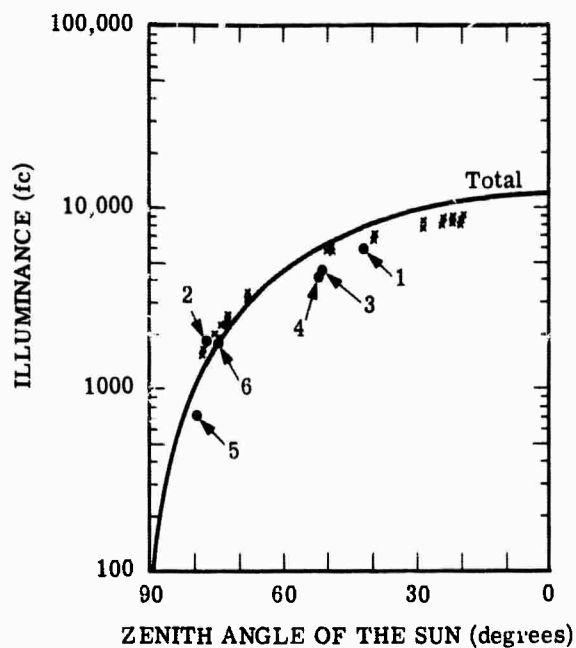


FIGURE 5. SPECTRAL IRRADIANCE FROM A FULL MOON AT A 60° ZENITH ANGLE COMPARED TO THE SPECTRAL IRRADIANCE FROM A MOONLESS NIGHT SKY

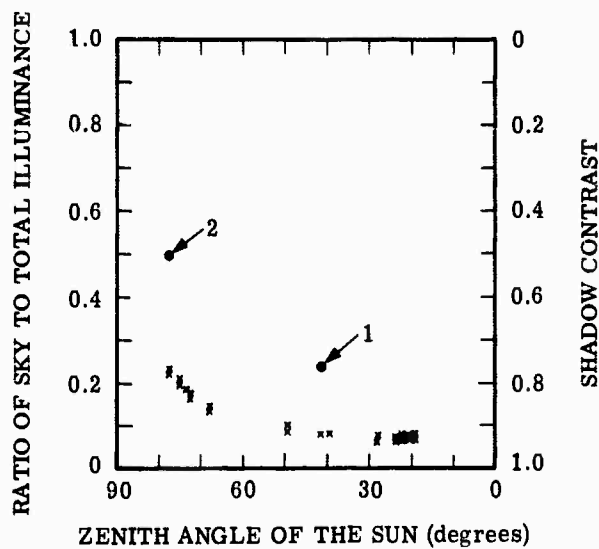
when present, is essentially the sole source of illumination, one expects clouds, haze, and overcast to have the same effects on moonlight as upon sunlight. Hence, this section has been derived from the wealth of data concerning visibility and daytime illumination as functions of cloud cover.

Brown's estimate of total daylight illumination on a horizontal surface for an average clear day, based on a large series of measurements on clear days, is not an estimate of just the direct solar illumination but includes the contribution of the skylight [20]. Thus, the estimates for moonlight illuminance in figure 4 already include the effect of scattered skylight for some average clear night (ground albedo, which does affect the sky illumination, has been neglected in Brown's work), and the following discussion therefore pertains to increases in the haze and cloud cover above this hypothetical average level.

Haze does not appear to decrease substantially the total illuminance but rather causes the source of illumination to be the entire sky [24]. The primary effect of haze, then, is the reduction of shadow contrast, as illustrated by figure 6; table I summarizes the data used in figure 6.



(a) Selected Measurements of Total Daylight Illuminance Plotted as a Function of Solar Zenith Angle



(b) Ratio of Sky Illuminance to Total Illuminance as a Function of Solar Zenith Angle for Some of the Data Plotted in Figure 6a.

FIGURE 6. THE EFFECT OF HAZE ON TOTAL ILLUMINANCE

TABLE I. DATA UPON WHICH FIGURE 6 IS BASED. Although isoluminance plots were presented in the references cited for all the results included in this table, only the data points labelled x, 1, and 2 had ratios of total to sky illuminance substantially different from unity; these are shown in figure 6b.

<u>Data Point</u>	<u>Reference</u>	<u>Location</u>	<u>Sky Condition</u>	<u>Ground</u>
x	24	Inyokern, California	Very clear	Unknown
1	24	Crestview, Florida	Clear; haze layer below 4000 ft	Unknown
2	25	Atlantic Ocean, off Patrick Air Force Base, Florida	Scattered clouds at 3000 ft; some cirrus above 20,000 ft; sun virtually unobscured	Ocean
3	28	Point Barrow, Alaska	Thin overcast	Snow; small patches of tundra
4	28	Point Barrow, Alaska	Overcast	Snow; 10% tundra
5	27	Bering Sea	Overcast	Snow-covered ice
6	27	Bering Sea	Clear	Snow-covered ice

Figure 6a shows illuminance as a function of solar zenith angle. Figure 6b shows, for the same data, the ratio of sky illuminance to total illuminance as a function solar zenith angle. The points indicated by x (fig. 6a and b), extracted directly from reference 24, were measured at Inyokern, California under very clear, dry conditions. Point 1 (fig. 6a and b), also taken from reference 24, was measured on a clear day in Florida with a haze layer below 4000 ft. It can be seen that although the total illumination at point 1 is almost identical to that at Inyokern, the sky makes a much larger contribution. Point 2 (fig. 6a and b) was measured over the Atlantic Ocean on an almost completely clear day [25]. Again the sky contribution is large compared to the Inyokern data, while the total illuminance is not significantly different.

The effect of overcast skies on illumination is described by Jones and Condit as a reduction in the illumination (1) by the square root of 10 for partial overcast and (2) by a factor of 10 for heavy overcast [26]. Points 3, 4, and 5 (fig. 6a) were measured under overcast skies [27, 28]. Since the total illumination for these points can be considered all skylight (the sun was obscured), the ratio that would be plotted in figure 6b is essentially unity. Unfortunately, points 3, 4, and 5 were all measured at high latitudes in areas of very high ground albedo (ice

and snow), and hence the illumination levels are probably higher than they would be under the normal albedo conditions in Southeast Asia and other low to middle latitudes. Since the effect of ground reflection on illumination level also depends upon cloud reflectivity, any estimate of the quantitative effect of ground albedo will be approximate. If a cloud reflectivity of 0.5 is assumed, the illumination of a perfectly reflecting ground is twice that of a perfectly absorbing ground; this factor increases as cloud reflectivity increases. The illumination levels observed on overcast days in the presence of high ground albedo are perhaps 70% of those observed on clear days (points 3, 4, 5, and 6 in fig. 6a) for comparable solar zenith angles. If the actual cloud reflectances when points 3, 4, and 5 were measured were somewhat greater than 0.5, the results might be considered not inconsistent with the values quoted by Jones and Condit [26].

No information could be found on the effects of cloud cover on the spectral distribution of lunar illumination. Any artificial illumination in the vicinity also contributes to the irradiance (as discussed in sec. 5.3) but is less important when the moon is full, because of the moon's brightness, than under very heavy overcast or when the moon is not full or is absent.

5.6. EFFECTS OF SURFACE ORIENTATION ON IRRADIANCE

Throughout this section the quantity that has been used to describe light levels is the total irradiance of an unobstructed horizontal surface. Although such a horizontal surface may not be a commonly encountered target, and although a surface oriented in another direction will not be illuminated in the same way, nevertheless, the quantity treated here appears to be the simplest way of describing the overall light level. Estimates of the irradiance of a surface oriented other than horizontally are possible, provided the radiance distribution of that portion of the sky seen by the surface is known. We have given such information for a clear, moonless night sky in this section. A distribution for the luminance of an overcast sky has been given by Moon and Spencer [29], but it does not fit the results of Hood [27], probably because of the high ground albedo present during Hood's measurements (again emphasizing the importance of this quantity to overcast illuminance). Clear sky luminance in the presence of a moon does not appear to have been measured. Measurements of clear sky luminance for specific times during the day are readily available [28, 30] and could be scaled down to moonlight levels. However, the apparent absence of a predictive model for the variation of sky luminance over the sky makes such a procedure less appealing. The contributions of other illumination features such as starlight and airglow are quite small compared to such luminance levels (except on very clear nights).

5.7. CONCLUSIONS

It is apparent at this time that we are not able to predict completely the irradiance levels existing at a given place and time. Although reasonable estimates of irradiance levels under

clear skies can be made, provided the lunar phase is known, the potential variability of the irradiance in the presence of overcast and its generally unknown spectral content make such predictions less valuable, particularly at locations where and during seasons when overcast is a common occurrence. Ground albedo, amount of cloud cover, and the presence of even distant sources of artificial illumination have all been shown to be important variables upon which the illumination depends even under partially overcast conditions.

The illumination of nonhorizontal surfaces and complex shapes is still more difficult to determine. Although reasonable estimates of such quantities under clear, moonless skies are possible, because sky radiance distribution is well known and generally nondirectional, such estimates under clear, moonlit skies are difficult in view of the variable ratio of direct to diffuse (sky) radiation.

The uncertainty that seems to be present in the values of full moon irradiance indicates that an effort might reasonably be undertaken to determine experimentally the lunar irradiance levels, especially since almost all of the lunar irradiance and illuminance values we now have are extrapolated from solar irradiance data. Observations of ground irradiance during overcast conditions would also be desirable if coordinated with careful notations of cloud cover, cloud height, ground reflectance, and, if at all possible, total sky photographs.

6

MEASUREMENT AND INTERPRETATION OF VISUAL PERFORMANCE

In order to predict the performance of night vision aids or to compare their performance with that of unaided humans, the basic procedures used to measure visual performance must be understood. These measurements do not constitute an exact science in the sense that visual performance cannot be defined by a simple function or quantity that can be accurately determined by repeatable, objective instrumentation. There are many variables, and numerous measurement procedures have been, and still are being used. This section discusses some of these procedures and the interpretation of the results obtained when they are used.

6.1. CRITICAL DIMENSION AND VISUAL ACUITY

The smallest dimension that can be seen is usually described in terms of its angular subtense at the eye, or rather the reciprocal of that subtense, which is called "visual acuity." To be certain that one has actually measured visual acuity, it is necessary to somehow ensure that the observer's perception depends unambiguously on one specific dimension; i.e., that dimension must be made a "critical dimension." Consequently, steps must be taken to eliminate all other possible visual cues.

The three basic types of visual tasks and corresponding visual acuities that have been identified are summarized in table II. Vernier acuity, an alignment task, does not seem relevant to night vision aids and therefore will not be discussed. It is not so easy, however, to judge the relative values of minimum visible acuity versus minimum separable acuity.

In testing for visual acuity, certain controls have typically been employed to "force" the observer's perception to depend upon one specific dimension. Generally, these controls are based on requiring more information from the observer than "Yes, I see it." or "No, I don't see it." The additional information sought may be one or more of the following:

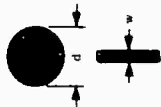
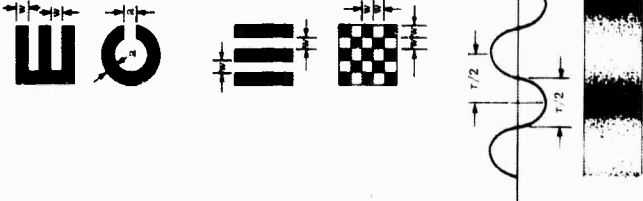

- (1) Identification of the shape of the object containing the specified dimension
- (2) Identification of the time interval in which the object containing the specified dimension appears
- (3) Identification of the orientation of test object containing the specified dimension
- (4) Identification of the location of test object containing the specified dimension

The first control is typified by the standard doctor's office examination where the task is to read various letters of the alphabet. While these letters are constructed so that their smallest dimensions (presumably the critical dimensions) and their contrasts are the same, it is known that some letters are more easily seen than others. Therefore, such tests do not depend unambiguously upon one specific dimension; other visual clues must be involved. (Beside gross structural differences, i.e., number and proximity of parts, these might include symmetry or lack thereof and the "angularity" of the letters.)

An example of the second test is the presentation of a disk in one of several time intervals. Two problems are associated with the time interval approach: First, it introduces an unwanted variable, (possible) dependence on memory. If the total number of intervals is not too great and the time span is not too long, one may argue that memory dependence is an insignificant factor; however, one cannot be absolutely certain. Moreover, one must have a fairly large number of intervals to reduce the probability of chance success to an acceptably low value (for this reason, two intervals would be completely unacceptable; usually, at least four intervals are used). Second, one must be sure that perception depends on actually seeing the test object used and not just sensing the presence of light.* To guard against the latter, one might present objects of different shape in the time intervals that had the same effect as did the correct interval on the observer in terms of the presence of light. The observer would then be required to identify

*The ability to sense the presence of light (the light sense) is much greater than the ability to perceive form (the form sense).

TABLE II. BASIC VISUAL TASKS AND CORRESPONDING VISUAL ACUITIES

Type of Acuity	Visual Task	Examples
Minimum visible acuity	Perception of an extended object, the boundary of which is such that its radius of curvature is never negative	 Disk: critical dimension is d. Bar: critical dimension is w.
Minimum separable (or minimum resolvable) acuity	Perception of either of the following: (1) A single extended object, the boundary of which is folded so as to bring parts of the object into close proximity (i.e., both positive and negative radii of curvature are required to define the boundary) (2) Two or more extended objects of the "minimum visible" type placed in close proximity (3) A continuously shaded object analogous to 2	 Snellen E: critical dimension is w. Landolt ring or C: critical dimension is a. USAF bar pattern: critical dimension is w. Checkerboard pattern: critical dimension is w. Sine-wave pattern: critical dimension is $\tau/2$.
Vernier acuity	Alignment	 Two pointers or a pointer and a scale marking: critical dimension is d.

the interval in which he saw the true test object. The difficulty is ensuring that the false objects are such that the critical dimension is the only clue to the identity of the true target. The use of true/false optotypes will be discussed more thoroughly when the location test is considered.

Examples of tests of the third type are those using the Landolt C, or the Snellen E, where the visual task is to state the orientation of the object. One problem with this approach is that it assumes perception is an isotropic process. Since this is known to be untrue, the tests are usually imprecise.* Moreover, it is not clear that no clues other than the critical dimension are being used, since results with the Snellen E and Landolt C are presently thought to differ.

In principle, the Landolt C or the Snellen E can be oriented in an infinite number of positions. In practice, however, the number of orientations is usually restricted to eight: N, NE, E, SE, S, SW, W, and NW, the only positions considered unambiguous enough to use in routine tests. If sine-wave or bar patterns are used, only four of the above orientations are unique: N-S, NE-SW, E-W, and NW-SE.

A classic example of control by identification of location, the fourth test, is the configuration shown in figure 7. The observer's task is to identify the location of the square of large

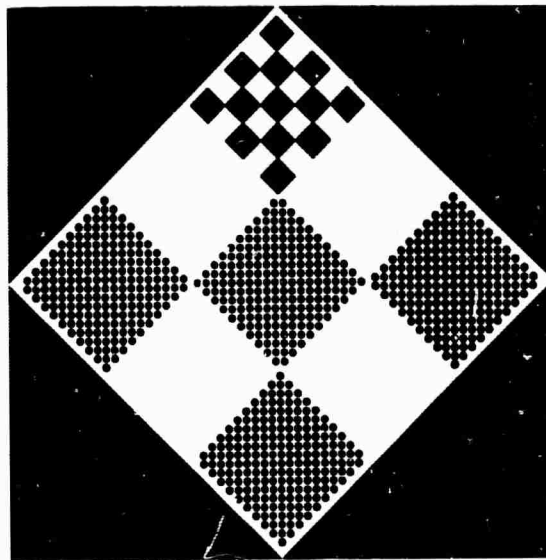


FIGURE CONTROL BY IDENTIFICATION OF LOCATION: THE CHECKERBOARD CONFIGURATION

*By suitably randomizing the orientations and optotype sizes, one could obtain visual acuity at each orientation used. This is not usually done, however, so that the anisotropy introduces a "systematic error."

checks. Presumably, when the entire configuration is brought to threshold (for example, by increasing the separation between it and the observer or by dimming the lights), both the large- and small-pattern checkerboards tend to wash out, ultimately appearing as equally gray, diamond-shaped patches of the same size. It is important to note that at threshold the overall shape and size as well as the shading of the two types of checkerboard are the same. The factors of shape, size, and shading having thus been eliminated as cues, the observer is "forced" to resolve the checks, thereby establishing a critical dimension. The deceptive targets in this test are false optotype correlates to the true optotype. Not all true optotypes admit to such correlates, however. At threshold the appearance of a Snellen E is perhaps best described as an amorphous blob. On the other hand, as a Landolt C is brought to threshold, the gap in the C tends to fill in, eventually producing a quite well defined annulus, the false optotype correlate of the Landolt C.

Whether acuity measured by the location approach is invariant from one set of true/false optotypes to another is presently unknown. In terms of reducing the probability of chance success to an acceptably low value, the location approach and time interval approaches are comparable. The location approach does seem less likely to involve a dependence on memory, however, since the entire configuration is in view during the observation period and can be "sensed" peripherally even while a part of the configuration is being carefully scrutinized. Nevertheless, the observer may have to remember what he has seen from one fixation pause to another, and therefore the location approach may also involve a memory dependence factor.

Two important questions are left unanswered: (1) how closely can one approach the ultimate goal of creating an optotype with a critical dimension, and (2) how do the results of various visual acuity tests relate quantitatively to each other? Clearly, the second question can be answered in a relatively straightforward manner, given enough data. Indeed, we are currently endeavoring to identify such quantitative interrelationships as have already been established.

Answering the first question is not quite so simple. If a comparison of data obtained by using different sets of true/false optotypes (say C's and rings versus checkerboards) were to reveal identical results, this would constitute strong circumstantial evidence that the goal had been achieved. To make such a comparison, however, may require that new data be generated and thus be beyond the scope of our effort.

Summary. To ensure that the observer's perception depends upon seeing a specified linear dimension, optotypes and test procedures that render the dimension critical must be devised. To accomplish this, false optotype correlates to true optotypes seem to be required.

With such sets of optotypes, either the time interval or the location approach can be used, but the latter seems preferable because it probably depends less on memory. Unless one is willing to accept some scatter in the test results, caused by the anisotropy of perception, the orientation of optotypes should be held constant. What constitutes an acceptably low probability of chance success varies with the demands of each experimenter.

6.2. CONTRAST

The commonly understood meaning of contrast, acceptable under normal visual conditions, is not suitable to the consideration of visual aids and illuminants with response outside the visual spectrum. It is therefore desirable to define contrast rigorously as a measurable quantity, which measurement should be useful to the calculation of system performance. We shall here compare the several definitions of contrast now being used and see how they are interrelated.

Contrast is basically a mathematical construct indicating the relationship between the quantities of electromagnetic radiation emanating from two parts of a scene. Contrast may be computed from differences in reflectivity, transmissivity, or in the case of a self-emitting object, emissivity. In terms of these parameters, contrast is invariant with illumination level but generally dependent upon the spectral distribution of illumination arising from the variation of the parameters with wavelength. Thus for the typical scene composed of two objects, contrast may be computed as a function of reflectivity or transmissivity, which are wavelength dependent. The contrast within this scene as seen by the observer is also a function of the illuminating spectrum and the spectral response of the observer's viewing device.

When emitted radiation is being measured, fluctuations may be observed, giving rise to statements about "fluctuations in contrast." While such statements are technically correct, they can be misleading as they do not make clear whether the fluctuations should be attributed to the energy source, the properties of the scene, or both. In our discussion such fluctuations will be attributed solely to the energy source unless otherwise noted.

Contrast is commonly measured by first taking the difference between the quantities of radiation emitted by the target and background and then normalizing this difference. Either value can be chosen as the subtrahend. In some mathematical formulations of contrast the lesser value is always chosen; the difference is then, of course, always positive and, ultimately, so is the quantity, contrast. Other formulations always choose as the subtrahend the value representing the background radiation; the difference, and hence contrast, is then positive or negative, according to whether the background is "brighter" than the target or vice versa. If a change in sign of the mathematical quantity called contrast were the only difference introduced

by this "background versus target" approach, the matter would be relatively straightforward: the sign would simply indicate which of the two, target or background, were "brightest." Unfortunately, in two popular mathematical formulations of contrast, a change in sign produces a radical change in kind in the quantity contrast itself. Our discussion of "background versus target" formulations of contrast is based on the "always positive" definitions of contrast that follow.

Four "always positive" formulations of contrast are presented in table III along with their analytical interrelationships. Figure 8 depicts these interrelationships graphically over a limited range. With the exception of one quantity for which no other name is known except Contrast (with a capital "C"), the suggested nomenclature for these quantities is derived from their history, their present usage, or both. Weber's Fraction, W , derived from Weber's Law is commonly used by psychologists and also appears in typical formulations of the DeVries-Rose quantum statistical theory of perception. Modulation, M , is the name now given to the quantity commonly used to describe the shading of spatial sine-wave patterns; it has generally replaced the older term, Visibility, originally introduced by Michelson in connection with the appearance of interferometric fringes. Density Difference (Photographic Contrast), ΔD , has its origin and major usage in work with photographic films, just as the name implies. It uses the difference between the logarithms of the two quantities of radiation rather than the difference between the quantities themselves. Using such a logarithmic measure appeals to some because of the presumably logarithmic relation between the human sensation of brightness and the physical intensity of light. Note that all four "always positive" definitions satisfy the criterion of being invariant with light level.

Now if one were asked to assign a numerical measure to contrast on a purely intuitive basis, one would probably suggest a positive quantity bounded to a range from 0 to 1 (or, equivalently, 0 to 100%). But of the definitions presented in table III, only two are bounded in this manner: Contrast and Modulation. Weber's Fraction and Density Difference are unbounded; as defined, they range from zero to infinity. It should be noted that when the unbounded quantities are used, a pure "black on white" or 100% contrast cannot be plotted on a conventional graph. The reader is cautioned to be particularly wary of graphs presented in the literature of psychology, which typically use the unbounded Weber's Function.

"Background versus target" definitions of contrast are summarized in table IV. The mathematical forms and nomenclature of the four "always positive" definitions are used, without regard, however, to the relative sizes of the parameters involved. The subscripts T, for target, and B, for background, indicate whether the target or background value is being used as the subtrahend (or, for ΔD , as the denominator).

TABLE III. INTERRELATIONSHIPS OF THE "ALWAYS POSITIVE" DEFINITIONS OF CONTRAST. The primitive concepts are as follows: $N_0 < N_1 < N_{00}$ represent the signal parameters; $(N_1 - N_0) > 0$ represents the signal; $R_1 = N_1/N_{00}$ and $R_0 = N_0/N_{00}$ represent reflectivity, R_1 ; $T_1 = N_1/N_{00}$ and $T_0 = N_0/N_{00}$ represent transmissivity, T_1 . Note the symbolic similarity between reflectivity and transmissivity.

CONTRAST	DEFINED IN TERMS OF	
	Signal Parameters	Reflectivity (similar for transmissivity):
Weber's Fraction, W	$W = \frac{N_1 - N_0}{N_0}$	$W = \frac{R_1 - R_0}{R_0}$
Contrast, C	$C = \frac{N_1 - N_0}{N_1}$	$C = \frac{R_1 - R_0}{R_1}$
Modulation (Visibility), M	$M = \frac{N_1 - N_0}{N_1 + N_0}$	$M = \frac{R_1 - R_0}{R_1 + R_0}$
Density Difference (Photographic Contrast), ΔD	$\Delta D = \log_{10} \left(\frac{N_1}{N_0} \right)$	$\Delta D = \log_{10} \left(\frac{R_1}{R_0} \right)$

INTERRELATIONSHIPS

Given				
Find	W	C	M	ΔD
W	—	$W = \frac{C}{1 - C}$	$W = \frac{2M}{1 - M}$	$W = 10^{\Delta D} - 1$
C	$C = \frac{W}{1 + W}$	—	$C = \frac{2M}{1 + M}$	$C = 1 - 10^{-\Delta D}$
M	$M = \frac{W}{2 + W}$	$M = \frac{C}{2 - C}$	—	$M = \frac{1 - 10^{-\Delta D}}{1 + 10^{-\Delta D}}$
ΔD	$\Delta D = \log_{10}(1 + W)$	$\Delta D = \log_{10} \left(\frac{1}{1 - C} \right)$	$\Delta D = \log_{10} \left(\frac{1 + M}{1 - M} \right)$	—

As indicated on table IV by an asterisk, contrast as represented by W and C actually changes from one type of quantity to another (W_B or W_T , C_B or C_T) depending on which parameter, target or background, is the largest. ΔD and M do not change in this way; they exhibit a change in sign only.

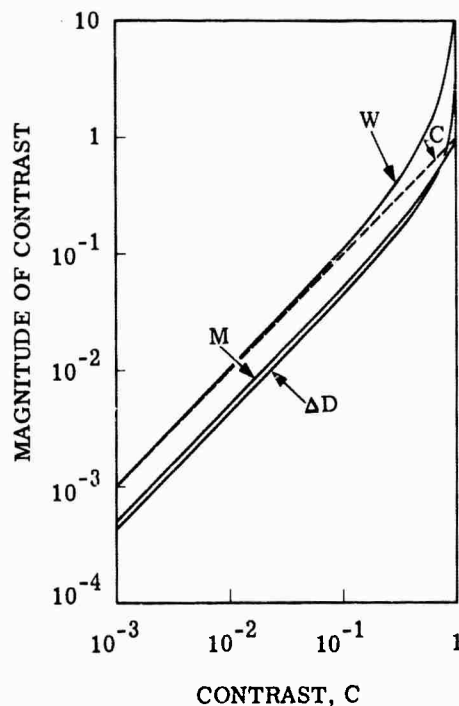


FIGURE 8. GRAPHICAL INTERRELATIONSHIPS
OF THE FOUR "ALWAYS POSITIVE" DEFINITIONS
OF CONTRAST

Is there any value in attaching a plus or minus sign to contrast? Often, as illustrated in figure 9, it is necessary to specify which portion of the scene constitutes the target and which is the background. In such an instance the use of a sign with contrast does not seem meaningful. On the other hand, there are circumstances where it may be very meaningful. For example, when if a small target appears against a large background, it may be desirable to indicate by the sign of contrast whether the target is darker than, or brighter than the background. Also, a change in sign may be useful in describing contrast reversals that occur, for example, with spurious resolution or in infrared versus visible light imagery.

If one desires to represent contrast by a quantity that (1) is bounded in absolute value to a range from 0 to 1 (0 to 100%) and (2) does not change in kind as its sign changes, then one should choose Modulation. If one is willing to forego the second constraint but not the first, then Contrast can be used. If one is willing to forego the first constraint but not the second, Density Difference should be chosen. If one is willing to forego both constraints, Weber's Fraction can be used as well as any of the other definitions. With any of the definitions, a plus or minus sign may be used to indicate contrast reversals. Finally, it should be

TABLE IV. "BACKGROUND VERSUS TARGET" DEFINITIONS OF CONTRAST AND THEIR RELATIONSHIP TO THE "ALWAYS POSITIVE" DEFINITIONS

"Background Versus Target" Definitions of Contrast		Relation to "Always Positive" Definitions of Contrast	
		$N_T > N_B$	$N_T < N_B$
Weber's Fraction, W	$W_B = \frac{N_T - N_B}{N_B}$	$W_B = W^*$	$W_B = -C^*$
	$W_T = \frac{N_B - N_T}{N_B}$	$W_T = -C^*$	$W_T = W^*$
Contrast, C	$C_B = \frac{N_T - N_B}{N_T}$	$C_B = C^*$	$C_B = -W^*$
	$C_T = \frac{N_B - N_T}{N_B}$	$C_T = -W^*$	$C_T = C^*$
Modulation (Visibility), M	$M_B = \frac{N_T - N_B}{N_T + N_B}$	$M_B = M$	$M_B = -M$
	$M_T = \frac{N_B - N_T}{N_T + N_B}$	$M_T = -M$	$M_T = M$
Density Difference (Photographic Contrast), ΔD	$(\Delta D)_B = \log_{10} \frac{N_T}{N_B}$	$(\Delta D)_B = \Delta D$	$(\Delta D)_B = -\Delta D$
	$(\Delta D)_T = \log_{10} \frac{N_B}{N_T}$	$(\Delta D)_T = -\Delta D$	$(\Delta D)_T = \Delta D$

*The quantity contrast exhibits a change in kind as well as in sign.

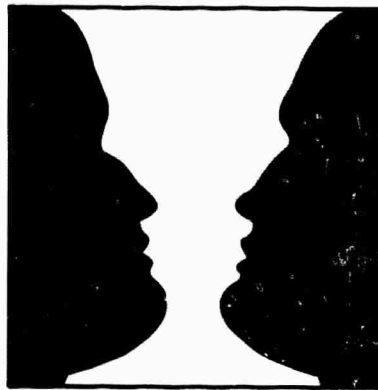
clearly stated whether fluctuations in contrast refer to fluctuations in the properties of the scene or in the energy source or in both.

6.3. QUANTUM FLUCTUATIONS AND PERCEPTION

The question of performance limits is fundamental to the selection and use of night vision aids. A review of the literature shows that this question is commonly answered theoretically in terms of "ultimate" limits that are set by quantum fluctuations. Analysis of the various treatments given this topic reveals a number of features that should be considered in continuing



(a) Black Bars on White Background or Vice Versa? A Similar Problem Exists for Spatial Sine-Wave Patterns.



(b) Facial Profiles or a Vase?

FIGURE 9. ILLUSTRATIONS OF THE NEED TO SPECIFY WHICH IS TARGET AND WHICH IS BACKGROUND

work. The most obvious but least important of these are the inconsistencies caused by the manner in which contrast is defined and parameters are eliminated from or retained in the formulas presented. Trivial as these things may seem, they tend to obscure the more important fact that there are fundamental differences in the mathematical rules being proposed and that these differences are bound to have important practical consequences. Also, individual

authors seldom evidence awareness of the approaches used by others or even indicate that the matter may be at issue. Similar statements, equivalent to "From any good handbook in statistics, it may be determined that . . . , " are often used as to establish foundations for quite different mathematical models.

It is primarily to illuminate these differences that the following summary is presented. It is not intended to promote one model as the "best" or to offer anything but an elementary comparison of the predictions of a few models with some empirical results. It focuses on the logical bases of the various formulations in order to show what implications and limitations to interpretation are inherent in the mathematical statements of each, to suggest possible extensions and new alternatives, and to demonstrate how these models could be tested empirically. To put it another way, we are not so much concerned with whether any of these models fit any empirical data as with what data, if any, they should fit.

To avoid losing the reader in a wealth of mechanical detail, models are presented in no more complicated terms than the numbers of photons absorbed in a primary photoreceptor; other complicating factors, such as veiling luminance, self-noise, etc., are deliberately omitted, although they would have to be included in a complete model. For more particulars, the reader is referred to the references cited in this section as well as the brief bibliography at the end of the report.

6.3.1. DOMAIN OF DEFINITION. Historically, the quantum fluctuation theory dealt with here was first introduced by DeVries and Rose in terms of photons impinging on or being absorbed in a primary photoreceptor, i.e, the photocathode of an imaging device or the retina of an eye [31, 32, 33]. Subsequently, when investigators became concerned with how fluctuations in input photons are propagated through an electronic imaging system and how they are supplemented by the self-noise of the system, electronics became the quanta of interest [34]. Recently, physiological studies were conducted to find out how photon fluctuations are propagated and combined with noise generated within the visual pathway [35]. Attention was focused on fluctuations in the number of discharges (electrical impulses) channeled down a nerve that is part of the visual pathway. The number of discharges qualifies as yet another type of quanta.

The foregoing examples illustrate part of what is meant in this section by "domain of definition," i.e., the type of quanta involved. Just which domain is the most important to a viewing process depends on the particular situation. In general, however, there seems to be agreement among advocates of fluctuation theory that it is the domain peculiar to that stage, often called the quantum sink, of the imaging process wherein the total number of quanta (with-

out regard to kind) is least relative to the other stages [36, 37, 38]. Obviously, whether input fluctuations or self-noise is of overriding importance also depends on the particular situation.

Domain of definition also includes recognition of the fact that the numbers of quanta upon which the theories are based are numbers per unit area. Whether such numbers are in themselves a sufficient basis, physically, for constructing a model seems debatable, as illustrated by the following argument. Under low light levels, when the area density of photons absorbed in the primary photoreceptor is very low, it is unlikely that two or more input photons would impinge upon one another during any brief interval. Thus, the pattern produced by the photons received during a brief interval could be represented simply as an array of dots. Figure 10 shows several examples. If the primary photoreceptor were the photocathode of an image tube and no self-noise were assumed in the tube, after amplification each dot of the pattern would presumably be rendered visible and, because of the spreading effects in the tube, would appear as a small "blob" of light. Since fluctuations in the number of quanta representing each dot of the absorbed pattern are introduced at several stages in the amplification process, the output blobs would vary in "brightness." Perceptually, the result would be a quite different visual impression of the image than that suggested by figure 10, and the difficulty of information extraction would probably be increased. To our knowledge, this effect is not taken into account in any fluctuation theory, and just how it might be is beyond the scope of this discussion.

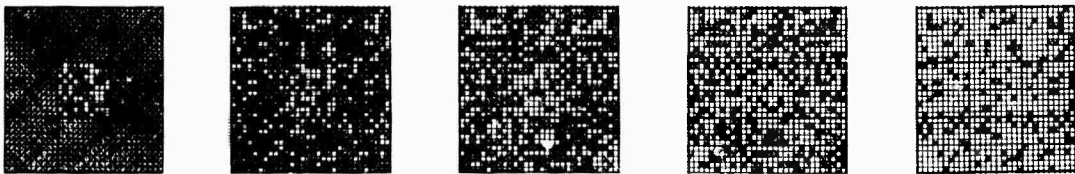


FIGURE 10. PATTERNS ILLUSTRATING HYPOTHETICAL IMAGES OF A BRIGHT SQUARE IN A DARK SURROUND UNDER LOW LIGHT LEVELS

6.3.2. DETECTION CRITERIA. In this section three examples of detection criteria are presented, but in general form, to emphasize their independence from any particular application. The first two criteria are known to have been previously proposed in connection with quantum models. The introduction of the third criterion is motivated by decision theory and by uncertainty about the biasing of human responses by the nature of the test object. In section 6.3.3. these criteria are rephrased in terms of the statistics of photons absorbed in a primary photoreceptor, but they could be applied equally well to different kinds of quanta that might exhibit different statistical properties (e.g., the nerve impulses from the photons absorbed in the

retina). In section 6.3.4 the third criterion is shown to yield a greater reduction in range with decreasing modulation than the other two.

The typical fluctuation theory is formulated as follows: Let N_1 denote the total number of quanta that are collected in an interval t from an image area. Let N_0 denote a lesser number of quanta collected in an area of equal size A over the same time interval t . Let the difference $N_1 - N_0$ be called the signal.

The fundamental hypothesis of fluctuation theory is that for perception to be possible the signal-to-fluctuation or signal-to-noise ratio (SNR) must equal or exceed some minimum value, which must be determined experimentally. Typically, one uses as a measure of fluctuation (noise) a standard deviation σ . Consistent with the above, at least three standard deviations and thus three SNR's can be defined:

$$\frac{N_1 - N_0}{\sigma_{(N_1 - N_0)}} = k_{1,0} \quad (1)$$

$$\frac{N_1 - N_0}{\sigma_{N_0}} = k_0 \quad (2)$$

$$\frac{N_1 - N_0}{\sigma_{N_1}} = k_1 \quad (3)$$

where k is an SNR. The fundamental hypothesis is applied to equations 1 through 3 by using the subscript operator \min to obtain the following "at threshold" criteria:

$$\frac{(N_1 - N_0)_{\min}}{\sigma_{(N_1 - N_0)}} = (k_{1,0})_{\min} \quad (4)$$

$$\frac{(N_1 - N_0)_{\min}}{\sigma_{N_0}} = (k_0)_{\min} \quad (5)$$

$$\frac{(N_1 - N_0)_{\min}}{\sigma_{N_1}} = (k_1)_{\min} \quad (6)$$

Note that the k_{\min} 's in equations 4 through 6, though different, can be easily related, given the different σ 's. Note also that \min applies only to the difference $N_1 - N_0$ on the left-hand

side of equations 4 through 6. As is shown in the next section, this is basically how the existence of a vision threshold is introduced into a quantum fluctuation model.*

Before the above criteria can be reformulated in terms of contrast to make them suitable for developing testable predictions, two interrelated aspects of the interpretation of equations 4 through 6, the mathematical and the perceptual, require further consideration.

First, a time factor, t , can be inserted into formulations 4 through 6 by the substitution

$$N = nAt \quad (7)$$

where n is a number of quanta per unit area and per unit time. The numerical value given to t is based on such things as the integration time of the eye, the frame time of an image orthicon, or the exposure time of a single frame of a movie. Thus, t represents the time required to obtain one single sample (but not necessarily the time needed to examine the sample). When values are assigned on this basis, however, normally no explicit rule is included to account for successive samples in time. It might therefore be inferred that successive sampling in time has no significance, except perhaps that an observer might see something in one interval but not another; it is assumed that his impression (if any) from one interval is not carried over to the next. That such a notion conflicts with reality seems obvious.

Mathematically speaking, t could be interpreted as the time given to collecting quanta, i.e., a factor that may be increased or decreased at will to yield a corresponding increase or decrease in ease of detectability. Even so, only one sample would be obtained in time.

Second, consideration must be given to the area, A . The areas that yield N_1 and N_0 are by definition of equal size and by implication of the same shape. Differences in shape, then, are automatically excluded as cues to perception; however, size is not excluded since A is variable. Nevertheless, predictions based on typical fluctuation models have been compared to empirical data in which shape is a factor—for example, the visibility of small objects (e.g., disks) embedded in a large, uniform surround—rather than to data involving, say, two such disks that differ in brightness. Also, when the former, incorrect comparison is made, it is inferred that a portion of the surround should be encircled by an imaginary boundary so as to enclose an area of the same size and shape as the object. Just which portion of the surround should be chosen is not clearly stated, although it is sometimes inferred that it must be contiguous with the object along a considerable length of the object's boundary (e.g., a square adjacent to a square). The latter would, of course, be impossible for some objects (for instance, disks).

*Historically, form 4 was the first proposed, originally by DeVries [31]. By considering the case where $N_1 \approx N_0$, DeVries also arrived at form 5, which Rose used in his work [32, 33].

Another interesting aspect of this uncertainty with regard to how area should be defined is even more fundamentally related to the mathematical nature of the quantities actually used in equations 4 through 6. Although a time average is implicitly ruled out, it is certainly possible mathematically and perhaps even perceptually that an average and a standard deviation for the large surround could be obtained by spatial sampling. Given enough samples, one could even imagine generating the distribution curve for the background or at least a histogram from which the distribution curve could be inferred. Alternatively, if the form of the distribution were known a priori, then the sample mean and standard deviation could be used to construct the specific distribution. One could then compare mathematically the suspected target area with the background to determine whether or not it is likely to be part of the background to some statistical confidence level.

In more specific, mathematical terms, the number of photons absorbed in a primary photoreceptor per unit area per unit time is known to follow a Poisson distribution, which in turn, for a large enough number of photons, can be well approximated by a Gaussian distribution. The optimum statistical procedure for testing the hypothesis that the mean of a normal distribution (\bar{N}_B , denoting the large background) has a specified value ($\bar{N}_B = N_T$, where N_T denotes the "target" photons) is based analytically upon a statistical test of the form

$$\frac{(\bar{N}_B - N_T)\sqrt{l}}{S} \quad (8)$$

where l is the number of samples and S is the sample standard deviation [39]. This expression, known as the student's t , is very similar to the left-hand sides of equations 5 and 6, since \bar{N}_B can be greater or less than N_T . Notice, however, that when $l = 1$ (when the background is the same size as the target), the expression is undefined since S is undefined:

$$S = \sqrt{\sum_{i=1}^l \frac{(N_{B_i} - \bar{N}_B)^2}{l-1}} \quad (9)$$

This is but a reflection of the fact that no "statistics" can be derived from the single comparison to which the typical mathematical formulation of quantum fluctuation limits of visibility is restricted, i.e., that N_B would either differ from N_T , or it would not. Rather than statistics, the typical formulation deals with probabilities, the "potential" that an event occurs.* This stems from the fact that σ is a true, not a sampled, value. In substituting for σ , one typically chooses a quantity that is a definite function of N_1 , N_0 , or both, which implies that any value

*This fact was perhaps first emphasized by R. Clark Jones [40], who also emphasized σ 's relevance to statistical decision theory. A recent, more theoretical treatment is that of J. L. Harris [41].

used for these quantities is also not sampled. More specifically, N_1 and N_0 are simply the expected values of stochastic variates, the distributions of which are known a priori.

Graphically, the situation can be depicted as in figure 11. To impose a detection criterion, one first chooses a reference, perhaps $P(N_0)$ in figure 11, and then chooses some decision threshold T with relation to the reference. For a fixed difference, $N_1 - N_0$, one can move the threshold along the axis and generate a graph of detection probability versus false-alarm probability, which is called a receiver operating characteristic (ROC). By changing the difference, one can generate a whole set of ROC's as shown in figure 12. With reference to this figure, as the signal (i.e., the difference) decreases from a high to a low value, the detection probability also decreases for a fixed false-alarm probability. If a greater false-alarm probability were acceptable, a constant detection probability could be maintained. One key question, then, is where should the threshold be placed (this is the probability counterpart of the statistical confidence level). A corollary question is to what extent does the human observer make a choice in placement.

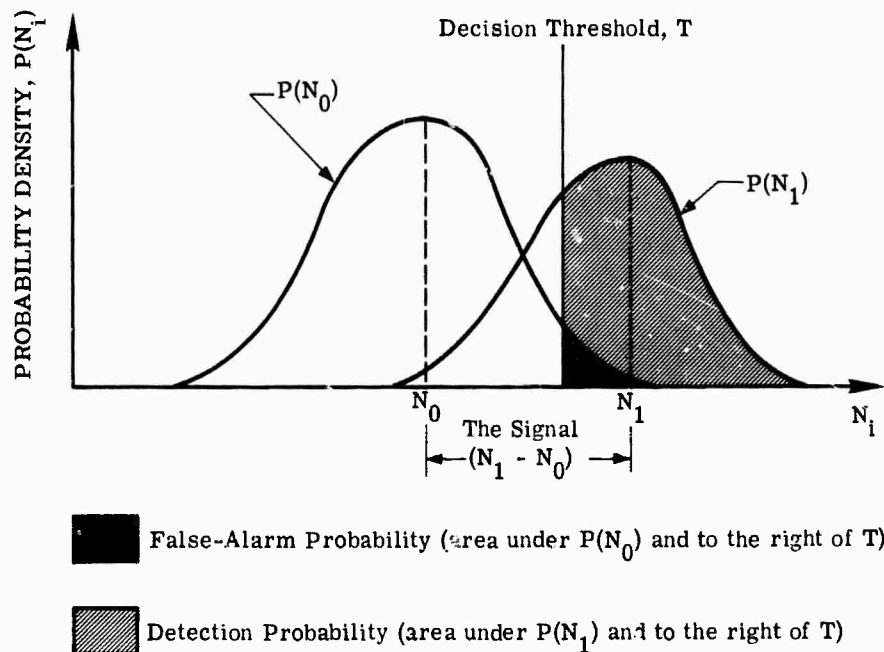


FIGURE 11. FALSE-ALARM AND DETECTION PROBABILITIES WHEN A DECISION THRESHOLD IS CHOSEN WITH RELATION TO $P(N_0)$

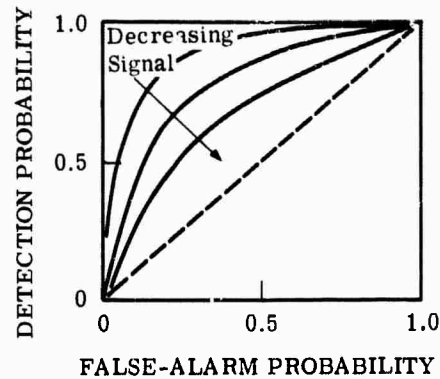


FIGURE 12. RECEIVER OPERATING CHARACTERISTICS FOR VARIOUS SIGNALS

The first question can be answered, or at least a mathematical solution indicated, by using what is called statistical decision theory [42]. It is necessary to introduce the concept of risk, which is defined as follows: First, suppose that each false alarm has associated with it a penalty or cost, C_f , and similarly for missing a true signal, a cost, C_m . Penalties C_f and C_m may not be equal. For example, in the decision of enemy versus no enemy, C_f may be only a wasted bullet, but C_m may be death. Second, suppose some known probability, e , that a signal (e.g., an enemy) will be present. Finally, let f be the false-alarm probability and m the probability of missing the signal (which equals one minus the detection probability). The risk associated with a false alarm is then defined as $(1 - e)C_f f$, the risk associated with the missed signal as $eC_m m$, and the average overall risk, R , as

$$R = eC_m m + (1 - e)C_f f \quad (10)$$

Strategies that may then be applied are:

- (1) The Bayes Strategy, which minimizes the average risk. It assumes that e , C_f , C_m , $P(N_0)$, and $P(N_1)$ are known.
- (2) The Minimax Strategy, which applies when e is unknown. By plotting the Bayes risk (the minimum average risk), $R(e)$, versus e and assuming "nature" (e.g., the enemy) would choose e so as to maximize its gain, the observer chooses the maximum value of the Bayes risk and thereby insures his losses will not exceed that value no matter what "nature" chooses for e .

(3) The Neyman-Pearson Strategy, which applies when e , C_f , and C_m are unknown. The observer determines a value of f that he can afford and that at the same time minimizes m . Actually, in figure 11, with known $P(N_0)$ and $P(N_1)$, no minimization of m is involved. When a decision is based on the outcome of several measurements, however, this is not so.

In the typical formulation the Neyman-Pearson Strategy is implicitly being employed. This follows from the fact that k is a constant. The other strategies cause k to depend on σ and the signal parameters N_1 and N_0 . A more detailed treatment of the mathematics is beyond the scope of this section. Just how one assigns risks and a priori probabilities are subjects requiring extensive analysis in themselves.

As to the question of whether or not such mathematical notions can be applied to the behavior of human observers, present indications are that in some sense they can be [43, 44]. Game theory experiments have indicated that an observer can alter his responses to maximize payoffs; however, a detailed review of this subject and its possible relation to quantum fluctuation theory is also beyond the scope of this discussion.

Most of the foregoing has been presented chiefly to provide a specific, concrete means of illustrating two major points: (1) No matter where the decision threshold is placed along the decision axis, only the value k_{\min} in the threshold equation is affected.* (2) Mathematically, it is the reference chosen that determines which σ to use. Using the Bayes, Minimax, or Neyman-Pearson Strategy simply imposes an added constraint on the placement of the threshold with regard to the reference; i.e., the strategy may affect the form of the criterion by establishing a relationship between k and σ such that k is not a constant.

Now, how are the criteria, equations 4 through 6, to be interpreted in terms of decision making? First of all, since the same time interval, t , is used, and since the areas corresponding to N_1 and N_0 are equal, the parameters compared are effectively n_1 and n_0 . Now, at least three decisions are conceivable, namely: (1) Do n_1 and n_0 differ? (2) Is n_1 "brighter" than n_0 ? (3) Is n_0 "dimmer" than n_1 ? These decisions correspond with equations 4 through 6, respectively. With reference to equation 5, the most commonly used criterion, as shown in figure 12 the difference $(N_1 - N_0)_{\min}$ must be some multiple, $(k_0)_{\min}$, times a measure of the spread, σ_{N_0} , in the reference N_0 at threshold. In other words, σ_{N_0} is used as a scaling factor to locate the position of the threshold. It can be used this way only because of its known functional re-

*The "correct value" of k has been debated by many writers. Originally, DeVries used $k = 1$ in equation 5 [31]. Later, Rose "experimentally" selected a value of 5 for k in equation 5 [33]. Still later, Sturm and Morgan suggested 3 to 6 [34]. Finally, Jones focused attention on how the variability of the numbers chosen was reflected in the probability of hits versus false alarms [40].

lation to N_0 . For equation 6, the situation is similar, except that N_1 is used as the reference, and the false-alarm and detection probabilities would be areas to the left of T . The pictorial interpretation of equation 4 would be one $P(N_1 - N_0)$ curve that overlapped zero on the N_0 scale but was offset to the positive direction with $T > N_0$.

Now, is there any reason to prefer one reference over the others? The answer would seem to be affirmative, especially since each criterion leads to somewhat different results as will be shown subsequently. But is one free to make the choice, and is this something that an unaware person would even consider doing? Is it not possible, instead, that there is something about the object viewed that biases the observer? For example, consider again the small target embedded in the large surround. Is it not at least plausible that an observer would be naturally biased toward using the largest area as the reference? And what about physiological light/dark adaptation? Because of the latter, the observer might be adapted to a light level that was some sort of average between the target and background, a level given, say, by the expression

$$\frac{n_B A_B + n_T A_T}{A_B + A_T} = n_{\text{adaptation}} \quad (11)$$

If this were true, two types of decisions could be involved, $n_T \geq n_{\text{adaptation}}$ and $n_B \geq n_{\text{adaptation}}$, or perhaps a single decision represented by $(|n_T - n_B| A_T)_{\min} = (k_{\text{adaptation}})_{\min} \sigma N_{\text{adaptation}}$.

It is interesting to note that the expression for the single decision degenerates to roughly the form of equation 4 in the event $A_B = A_T$. The main point is that testable prediction can be developed that ultimately lead to the selection, in section 6.3.4, of an appropriate reference.

Whatever the reference and whatever the strategy, in treating a small target embedded in a large surround, the same kind of interpretative problem arises when we deal with probabilities as when we deal with statistics, namely, how many comparisons are made. If only one comparison is made, as the form of equations 4 through 6 implies, which part of the background should be used? If more than one comparison is made, just how many can be made, typically are made, or should be made? Whatever the case, the mathematical form of equations 4 through 6 would have to be modified accordingly. As it stands, that only one comparison is made must be inferred.

6.3.3. SUBSTITUTION FOR NOISE AND REFORMULATION IN TERMS OF CONTRAST.

After selecting a decision criterion, i.e., a reference and a strategy, the next step in constructing a quantum model is the actual substitution for σ in terms of N_0 , N_1 , or both. What form this substitution should take depends upon the stage of the imaging process. For purposes

of this discussion, only the fluctuation in the number of photons absorbed in the primary photocathode is considered. Since this number follows a Poisson distribution,

$$\sigma_{N_0} = \sqrt{N_0} \quad (12)$$

$$\sigma_{N_1} = \sqrt{N_1} \quad (13)$$

and since N_0 and N_1 are statistically independent,

$$\sigma_{(N_1 - N_0)} = \sqrt{N_1 + N_0} \quad (14)$$

Substitution into equations 4 through 6 yields

$$\frac{(N_1 - N_0)_{\min}}{\sqrt{N_1 + N_0}} = (k_1, 0)_{\min} \quad (15)$$

$$\frac{(N_1 - N_0)_{\min}}{\sqrt{N_0}} = (k_0)_{\min} \quad (16)$$

$$\frac{(N_1 - N_0)_{\min}}{\sqrt{N_1}} = (k_1)_{\min} \quad (17)$$

where N is again an expected value.

The decision criteria are now in a form suitable for reformulation in terms of contrast. Table V presents each criterion in terms of the "always positive" definitions of contrast (sec. 6.2) with either n_0 or n_1 eliminated from the expression. When it is recalled that the "background versus target" definitions of contrast could also be used, it becomes clear from table V that a large number of such "laws" could be written. These would differ from one another, however, only in terms of the reference and strategy used—which definition of contrast is chosen is incidental, not fundamental, as is the elimination of n_0 or n_1 from the expressions. The choice of which to eliminate may be regarded simply as a matter of mathematical convenience or perhaps be made to emphasize the quantity that is measured (usually the greater, n_1 , since n_0 may be very low and measurements thereof unreliable).

The reader is cautioned against judging differences in the "laws" given in table V by a straightforward comparison of their left-hand sides. Even though the forms are similar, it is reemphasized that k differs from one criterion to another.

TABLE V. DETECTION CRITERIA IN TERMS OF THE "ALWAYS POSITIVE" DEFINITIONS OF CONTRAST. The domain of definition is the number of photons absorbed in a primary photoreceptor. The strategy used is the Neyman-Pearson. $N_1 \geq N_0$ and $\sigma_{N_1}^2 = \sqrt{N_1}$. The comparison is limited to two equal areas.

	Reference: N_0		Reference: N_1		Reference: $N_1 - N_0$	
	Criterion: $(N_1 - N_0) = k_0 \sqrt{N_0}$		Criterion: $(N_1 - N_0) = k_1 \sqrt{N_1}$		Criterion: $(N_1 - N_0) = k_{1,0} \sqrt{N_1 - N_0}$	
	Retaining N_1	Retaining N_0	Retaining N_1	Retaining N_0	Retaining N_1	Retaining N_0
Weber's Fraction, W	$\frac{W}{1+W} \sqrt{N_1} = k_0$	$W \sqrt{N_0} = k_0$	$\frac{W}{1+W} \sqrt{N_1} = k_1$	$\frac{W}{1+W} \sqrt{N_0} = k_1$	$\frac{W}{\sqrt{2-W}(1+W)} \sqrt{N_1} = k_{1,0}$	$\frac{W}{\sqrt{2-W}} \sqrt{N_0} = k_{1,0}$
Contrast, C	$\frac{C}{1-C} \sqrt{N_1} = k_0$	$\frac{C}{1-C} \sqrt{N_0} = k_0$	$\frac{C}{1-C} \sqrt{N_1} = k_1$	$\frac{C}{1-C} \sqrt{N_0} = k_1$	$\frac{C}{\sqrt{2-C}(1-C)} \sqrt{N_1} = k_{1,0}$	$\frac{C}{\sqrt{2-C}} \sqrt{N_0} = k_{1,0}$
Modulation, M	$\frac{2M}{1+(1-M)} \sqrt{N_1} = k_0$	$\frac{2M}{1-M} \sqrt{N_0} = k_0$	$\frac{2M}{1+M} \sqrt{N_1} = k_1$	$\frac{2M}{1+M} \sqrt{N_0} = k_1$	$\frac{M\sqrt{2}}{1+M} \sqrt{N_1} = k_{1,0}$	$\frac{M\sqrt{2}}{1+M} \sqrt{N_0} = k_{1,0}$
Density Difference, ΔL	$\frac{(10^{\Delta D} - 1) \sqrt{N_1}}{\sqrt{10^{\Delta D}}} = k_0$	$(10^{\Delta D} - 1) \sqrt{N_0} = k_0$	$\frac{(10^{\Delta D} - 1) \sqrt{N_1}}{\sqrt{10^{\Delta D}}} = k_1$	$(10^{\Delta D} - 1) \sqrt{N_0} = k_1$	$\frac{1 - 10^{-\Delta D}}{\sqrt{1 + 10^{-\Delta D}}} \sqrt{N_1} = k_{1,0}$	$\frac{1 - 10^{-\Delta D}}{\sqrt{10^{-\Delta D}(1 - 10^{-\Delta D})}} \sqrt{N_0} = k_{1,0}$

6.3.4. TESTABLE PREDICTIONS. Given the criteria outlined above, how is one to decide which, if any, is applicable to a given situation? As stated earlier, it would seem that each can be tested and a decision predicated on the results. In this section some possible tests are enumerated, with special emphasis given to an example that illustrates the differences among the criteria within a single, simple, but important, context, the decrease in detection range with a decrease in contrast.

Possibly the most complete test of the applicability of each criterion would be the generation of an empirical ROC. To do this would probably require a game theory experiment complete with penalties and rewards and perhaps known probabilities to encourage observers to shift their thresholds (k values). But the complexity of this approach causes us to seek simpler alternatives.

Because k (the decision threshold) probably varies from observer to observer according to physiological and psychological differences, as well as varying in time for an individual observer, it seems desirable to eliminate this factor. By assuming that an individual observer can be and usually is consistent for at least short periods (i.e., keeps a constant k), the precise position of the threshold, whatever it is, can be eliminated from consideration by comparing detection under two different sets of contrast, brightness, size, and time conditions.

Inspection of the various expressions for the criteria in table V reveals that each has the form

$$(\text{term involving only contrast})\sqrt{N} = k$$

The first set of conditions having been denoted by the subscript x and the second set by the subscript y , the assumption of constant k may be expressed as:

$$(\text{term involving only contrast})_x \sqrt{N_x} = (\text{term involving only contrast})_y \sqrt{N_y} \quad (18)$$

Of the factors n , A , and t that comprise N , n is usually not measured directly; hence it seems desirable to replace n if possible with quantities that are. When we deal with photons being absorbed in the photocathode of an image tube, N can be conveniently rephrased in terms of detection range and scene brightness as follows. If a small object area normal to and on the axis of the objective lens ahead of the photocathode behaves as a Lambertian source,

$$N \approx n_{\omega} \Delta A t \theta \frac{\pi R^2}{r^2} \quad (19)$$

where n_{ω} = number photons emitted normal to the surface per unit area per unit time per steradian

ΔA = magnitude of the area

R = radius of the aperture stop (e.g., the diameter of the objective lens)

r = distance between the lens and object

θ = a number, less than one, that accounts for lens transmission, photocathode quantum efficiency, etc.

$r \gg R$

Substituting equation 19 into equation 18 yields

$$\left(\begin{array}{c} \text{term involving} \\ \text{only contrast} \end{array} \right)_x \left(n_{\omega} \Delta A \theta \frac{\pi R^2}{r^2} \right)_x = \left(\begin{array}{c} \text{term involving} \\ \text{only contrast} \end{array} \right)_y \left(n_{\omega} \Delta A \theta \frac{\pi R^2}{r^2} \right)_y \quad (20)$$

From inspection of equation 20, it is evident that if contrast is a constant (and thus so is the term involving only contrast), any variation in detection range is independent of the criterion. On the other hand, a change in contrast could be reflected in a criterion-dependent change in any of the other variables. Of these, r is generally easy to measure and can by itself reflect the entire change in a sufficiently sensitive way as to determine our choice of a criterion.

To take advantage of the lack of mathematical ambiguity in the Modulation definition of contrast and of some available experimental data, we choose the basic relationships given in terms of M and N_0 in table V to develop testable predictions. From these it is possible to derive the following relationships for the references indicated:

$$N_0: \frac{r_y}{r_x} = \left(\frac{M_y}{M_x} \right) \left(\frac{1 - M_x}{1 - M_y} \right) \quad (21)$$

$$N_1: \frac{r_y}{r_x} = \left(\frac{M_y}{M_x} \right) \sqrt{\frac{(1 + M_x)(1 - M_x)}{(1 + M_y)(1 - M_y)}} \quad (22)$$

$$N_1 - N_0: \frac{r_y}{r_x} = \left(\frac{M_y}{M_x} \right) \sqrt{\frac{1 - M_x}{1 - M_y}} \quad (23)$$

From inspection of equations 21 through 23 it is easily verified that if $M_y > M_x$, then $r_y > r_x$ and visa versa. By using the references as suffixes to identify each of the above ratios, it can be shown that

$$\frac{\left(\frac{r_y}{r_x} \right)_{N_1}}{\left(\frac{r_y}{r_x} \right)_{N_0}} = \sqrt{\frac{(1 - M_y)(1 + M_x)}{(1 - M_x)(1 + M_y)}} \quad (24)$$

$$\frac{\left(\frac{r_y}{r_x}\right)_{(N_1 - N_0)}}{\left(\frac{r_y}{r_x}\right)_{N_0}} = \sqrt{\frac{1 - M_y}{1 - M_x}} \quad (25)$$

$$\frac{\left(\frac{r_y}{r_x}\right)_{N_1 - N_0}}{\left(\frac{r_y}{r_x}\right)_{N_1}} = \sqrt{\frac{1 + M_y}{1 + M_x}} \quad (26)$$

From equations 24 through 26, for the condition that $M_y < M_x$, it can be deduced that

$$\left(\frac{r_y}{r_x}\right)_{N_0} < \left(\frac{r_y}{r_x}\right)_{(N_1 - N_0)} < \left(\frac{r_y}{r_x}\right)_{N_1} \quad (27)$$

That is, using N_0 as a reference would yield the greatest reduction in range, $N_1 - N_0$ the second greatest, and N_1 the least reduction.

While not at all to be taken as conclusive evidence for a variety of reasons—not least of which is the failure to account for the modulation transfer function—it is interesting to note that in our field tests of the Starlight Scope, which looked at black bars on either a white or grey background, the decrease in detection range with modulation appeared to fit the criterion formulated by using the higher background value as a reference (eq. 6) better than it did the other criteria.

7

EVALUATION OF EYEGLOSS AND THE WIDE FIELD OF VIEW STARLIGHT SCOPE

As part of this contract, WRL has been asked to prepare a program of evaluative tests to be performed by ARPA outside the continental United States. Two devices are to be evaluated, the first of which, EYEGLOSS, was developed by EOS. It is based on the Night Observation Device (NOD) now in production. The EYEGLOSS is designed for airborne reconnaissance from relatively slow helicopters and fixed-wing aircraft. It incorporates an image-motion compensation system to reduce the effects of vibration and small perturbations from straight-line

flight. The unit is entirely self-contained and is designed to be rapidly mounted in a number of aircraft.

The second device is the Wide Field of View Starlight Scope, also developed by EOS. It is a conventional starlight scope modified to provide different fields of view ranging from a maximum of 40° down to the standard 10° by means of readily interchangeable objective lenses.

These devices will be evaluated in the field, presumably in Southeast Asia, according to the plan devised by WRL.

A number of preliminary measurements and experiments will be performed at WRL before and while the test plan is being formulated so that an efficient plan can be written, one excluding needless tests yet including all measurements necessary to a satisfactory evaluation. These early experiments also will help assure the success and reliability of the procedures for instrumentation, conducting the tests, recording data, etc. and will minimize last minute changes in the field.

These preliminary experiments give rise to a number of secondary objectives, which in themselves will result in data useful to the continuing program:

- (1) Data concerning the technical performance of both devices will be obtained, including laboratory measurements of acuity as a function of light level and contrast. Similar measurements will be made under field conditions.
- (2) Field data relating acuity to recognition of live targets will be obtained as a first attempt to relate acuity to perception.
- (3) By varying the size and contrast of the technical target (probably a Landolt C), it should be possible to obtain contrast-versus-size trade-off data that apply to the entire system of men and instruments.
- (4) The study of human factors will largely involve observation of major problems of human engineering or limitations of human performance. There will also be limited experiments to measure air search rates and search rate as a function of field of view and field of search. There will also be an opportunity to compare the performance of several operators under very nearly identical conditions.

To attain these objectives, five steps have been proposed, involving both field and laboratory work as well as formulation of the test plan itself. These five steps are presented below in their logical time sequence; however, this is not meant to imply that they must be followed in completely serial manner. To the contrary, there will be considerable overlap in some instances.

Step 1: Familiarization Organization. This step combines becoming acquainted with the expected performance of each device in a very general way, disposing of the problems of mounting the equipment in the aircraft, and planning the more practical, less theoretical work of step 2.

Step 2: Laboratory and Field Measurement of Equipment Characteristics. Before a reasonable test plan can be formulated, the performance to be expected of the devices must be known in some detail. Otherwise, field tests would be very inefficient and might not test all characteristics adequately. Such knowledge, plus the checkout described under step 4, should serve to keep the actual field tests as simple and informative as possible and should greatly reduce the need for last minute changes after the tests begin.

Laboratory tests will be conducted to determine such factors as resolution, brightness gain, field of view, and operating characteristics as they relate to human factors. Whenever data are already available, the WRL tests will be kept to an absolute minimum and will serve only to establish that the equipment is still performing correctly.

Following the laboratory measurements there will be a series of field experiments to determine performance under operational conditions. The first field tests will be equivalent to those made in the laboratory and will include measurements of sensitivity and acuity and observations of human factors problems.

It is thought that by means of a short-range radar tracking system rather accurate measurements of range to the aircraft can be made for EYEGLOSS by WRL. The radar antenna will also serve to support a Landolt C ring that will be used as the target. In this way the plane of the target can be kept normal to the line of sight. The EYEGLOSS device, which will be carried in a C-47, will be tested under illumination ranging from near starlight to full moonlight. Photometric measurements will be made of target and background radiance and of irradiance, which should result in curves of acuity versus light level with contrast as a parameter. During these measurements of acuity we shall attempt to relate the acuity data to the ability to recognize various "real" targets such as men or small vehicles.

Limited search-effectiveness experiments will be made, but only as they are needed to plan the final test procedure.

For the WFOV, there will also be a series of laboratory measurements of brightness gain, acuity, and field of view, with attention being given to the operator's problems in using the equipment. Again, available results of previous tests will be used wherever possible. Field tests will first use optotypes such as the Landolt C, and, as for EYEGLOSS, an attempt will be made to relate recognition of "real" human targets to acuity measurements. Limited search-

effectiveness tests will be carried out in an effort to relate field of view, detection range, and field of search.

Step 3: Establish Test Procedure for Use in Southeast Asia. There are two major decisions to be made at this point: (1) instrumentation and control procedures and techniques must be selected, and (2) general types of target/background environments must be chosen.

It has been assumed that relatively simple instrumentation must be used and that a large staff of skilled technicians will probably not be available. Even so, it is necessary to measure irradiance levels, ranges between observer and target, target distribution, and the aircraft's flight path. Also, it must be possible to establish that the vision aid is performing correctly before and after each data-taking operation.

The use of radar (see step 2) will make possible accurate measurements of range and flight path at WRL. Assumedly, radar will not be available in Southeast Asia, and therefore simpler procedures based on the use of beacons to indicate the flight path to be followed and perhaps very simple, ground-based optical sighting devices in the vicinity of the target complex will be used. Photometric measurements should also be made, but they probably cannot be as numerous or accurate as those made at WRL in the preliminary work. A set of resolution (acuity) targets should be included in each scene to help relate a given set of conditions to earlier measurements made in either the continental United States or Southeast Asia.

In the interests of obtaining useful data in a reasonable period of time and within a limited budget, the target complex must be restricted to a relatively small number of variables. In general, the targets will be humans, both stationary and moving, and perhaps fleeting as well, if time permits. A small number of vehicles may be used, but human targets will be emphasized. Several typical backgrounds must be used for each type of target, and, of course, data should be gathered under several kinds of illumination.

EYEGLOSS, which is airborne, should be evaluated in terms of its usefulness in reconnaissance of trails, roads, and large areas and also in detailed scrutiny of a known small area, but just how this will be done has not been decided. Its reconnaissance performance will probably be evaluated by establishing a target complex and a flight profile and then attempting to score the probability of detection. The evaluation of EYEGLOSS is further complicated by the fact it could be flown in any of several aircraft, all of which have quite different mounting configurations and flight characteristics. It is very difficult to see how a complete evaluation can be carried out without trying all of them. Perhaps certain combinations of target complex and aircraft can be ruled out.

Evaluation of the ground-based WFOV will be considerably simpler. Measurements are easier to make, control easier to maintain, ranges smaller, and of course the observer is in a fixed location rather than airborne. Emphasis will be on comparing probability of detection or range of detection for various combinations of field of view and field of search. As in the EYEGLOSS evaluation, the targets will be human beings, stationary, moving, and perhaps fleeting, and various representative backgrounds will be used.

Step 4: Checkout of Test Procedures for Southeast Asia. Some of the procedures for recording of measurement data, control, communication, operator indoctrination, etc. selected under step 3 will need to be checked by mock-testing at WRL. Such dry runs should considerably enhance the probability of success of the actual evaluation in Southeast Asia. In addition, the liaison with ARPA and any supporting organization should have determined by this time that the test plan is feasible and can be implemented.

Step 5: Formulation of the Final Test Plan. At this point the actual, detailed test plan will be prepared—in elaboration of the plan arrived at in step 3, plus any modifications that may result from the work of step 4. The level of detail has not been established and will depend to some considerable extent on the time scale and the availability of information concerning facilities, personnel, etc. in Southeast Asia.

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Appendix
SOURCES OF TARGET AND BACKGROUND DATA

The objects measured and number of reflectance curves given are presented at the end of entries in the following listing when they are known.

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13. ABSTRACT The first year's effort was devoted primarily to a measured buildup of staff and accumulation of background information for use in the continuing program. A library of technical reports was assembled and catalogued. Target and background data were assembled and reviewed for application to the problems of night vision. Also collected were data concerning the characteristics of illumination from the night sky. Investigation of the ability to predict target visibility from these data was initiated. Currently, plans for field evaluation of the EYEGLOSS and Wide Field of View Starlight Scope (WFOV) devices are being prepared; preliminary field experiments with EYEGLOSS are underway. As part of an investigation of visual differences among people in different parts of the world, a subcontract is being negotiated with the American University of Beirut (AUB) for a survey of visual acuity and dark adaptation among their students. Relationships among the various means of measuring acuity are being investigated in order to select the technique(s) most useful in predicting night-viewing performance under real-world conditions. An experimental color-viewing device that operates at low light levels is also being investigated. Plans for the coming year include completion of the preliminary field measurements on EYEGLOSS and WFOV and initiation of the evaluative tests by ARPA, active work on the AUB subcontract and a related measurement program at WRL, field work to develop relationships between field performances and measured characteristics, and experimental work with the color-viewing device. The primary objective of the program will continue to be the development of improved capability to calculate night-viewing system performance from measurements of system components and the target environment.			

14.

KEY WORDS

LINK A

LINK B

LINK C

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